WORKING PAPERS
FOR A
RENEWABLE ENERGY PROJECT
IN
SENEGAL

MARCH 1979

CENTER FOR RESEARCH ON ECONOMIC DEVELOPMENT
UNIVERSITY OF MICHIGAN

INTRODUCTION

These working papers for a renewable energy project in Senegal were drafted by members of the Project Paper team that worked in Senegal from November 7 to December 20, 1978. The team consisted of:

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As it stands, the project described in the following pages will not be submitted to AID/Washington. Some items of information gathered and the analysis performed by the team may be useful nonetheless. Draft sections of what might have been a Project Paper are therefore being reproduced as working papers. The reader will see that certain sections are missing or incomplete. Others would need revision or further editing if they were to be submitted as parts of a Project Paper.

The work of the team and the preparation of these papers were carried out under work order number 21 of Indefinite Quantity Contract number AID/afr-C-1143 issued to the Center for Research on Economic Development of the University of Michigan.

Ann Arbor, Michigan
March 16, 1979

Reprinted
May 1979

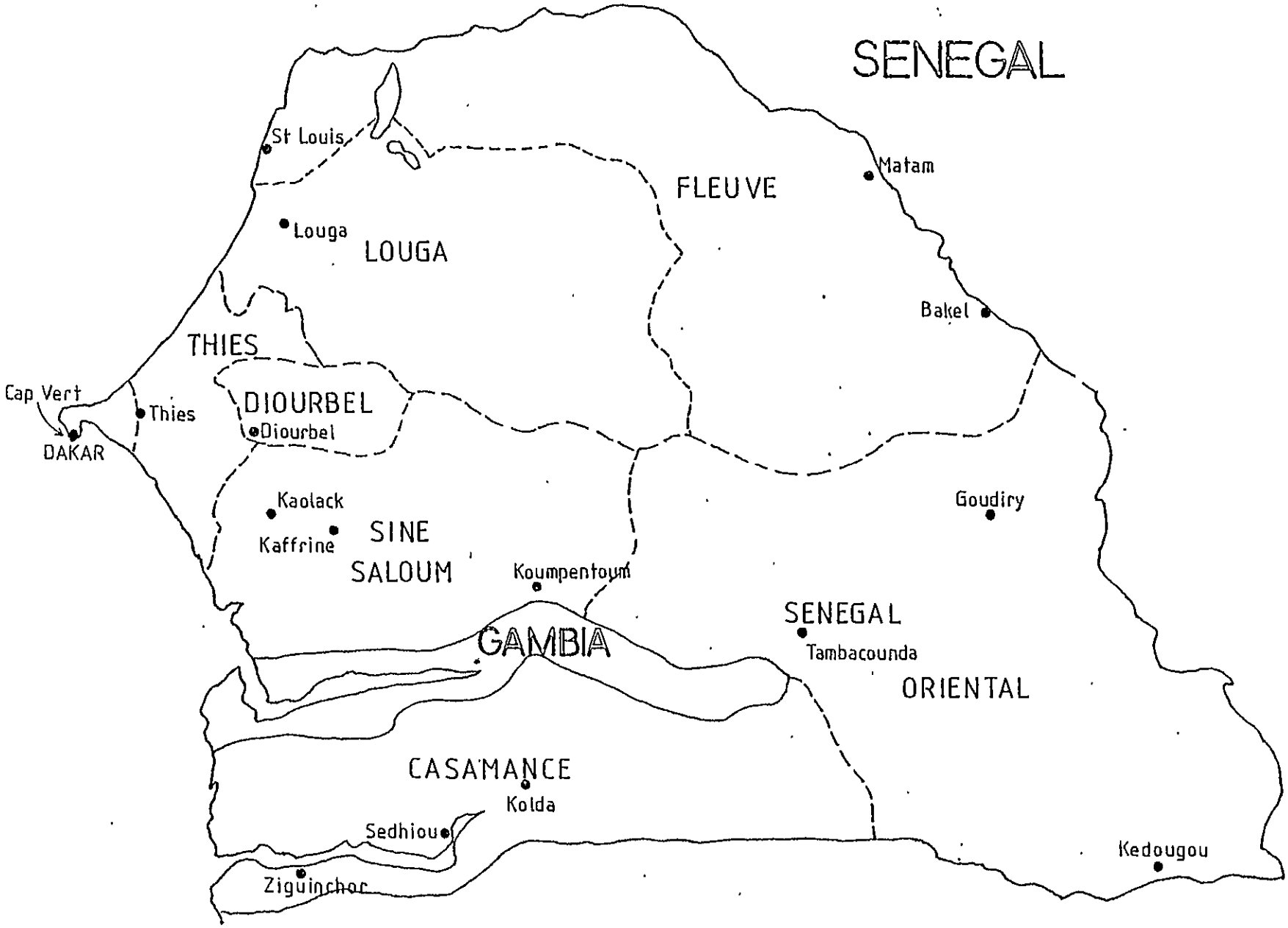
TABLE OF CONTENTS

I.	Project Description	page 1
II.	Social Soundness Analysis Summary	14
III.	Technical Analysis Summary	19
IV.	Environmental Concerns	24
V.	Proposed Budget	25
VI.	Implementation Plan	27

APPENDICES

A. Energy Sources and Uses in Senegal

B. Technical Analysis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ORIENTAL
GAMBIA
Tambacounda
CASAMANCE
Kolda
Sedhiou
Kedougou
Ziguinchor

I. PROJECT DESCRIPTION

The project proposed in this paper is a scaled-down version of the one identified by the Overseas Development Council and described in a Project Identification Document dated March 1978. It is based on some assumptions that should be made clear at the outset. First, the Project Paper team defined renewable energy to mean energy produced directly by sun, wind and biomass. Human and animal metabolic energy were excluded, and hence there is no proposal in this paper for hand pumps, animal driven pumps, or other devices of a similar nature. Second, the team assumed that the project would be essentially experimental without being academic. This means that the technologies proposed need to be practical, aimed at alleviating important tasks undertaken by the rural population and making rural life more productive. At the same time it should be recognized that some crucial questions need to be answered about these technologies before they can be considered proven enough to warrant much wider use. The aim of the project is to seek answers -- technical, economic and social -- in a systematic fashion. Third, realizing how little is known with precision about the use of non-commercial sources of energy in rural Senegal, the team considered it important to make sure that sharply focused site surveys be conducted both to find out about energy use and to establish baseline data for later evaluations of the impact of the new technologies. At the same time, the team found that socio-economic studies are routinely conducted in many rural areas. They should be exploited and not duplicated; their existence can significantly reduce the time devoted to site surveys.

The fourth and final assumption is worth emphasizing. It is expensive to introduce new technologies and adapt them to the realities of village life. The budget proposed for the project contains substantial research and development expenditures that reflect this fact. Once various devices have been tested and proven, if indeed they can be, the cost per unit when installed in quantity will be much lower. Judgments about their economic viability cannot therefore be made on the basis of the costs that will be incurred to develop, build and test a prototype.

While none of the applications of solar, wind. and biomass energy are ready for widespread installation in Senegalese villages, each of them holds promise for the 1980s. Those that are able to prove themselves technically, economically and socially could be counted on to answer some of rural Senegal's pressing energy needs in the next decade.

The applications to be installed and tested are:

1. Solar fish dryers,
2. Improved woodburning stoves,
3. Photovoltaic pumps to provide water for human and animal consumption and for irrigation,
4. Photovoltaic village power supply for a combination of uses: grinding grain, pumping water, refrigeration and lighting,
5. Biodigestion of animal wastes to produce methane gas for powering water pumps and refrigeration units,
6. Solar hot water heaters for rural dispensaries and maternities,
7. Windmills for pumping water.

Four of these applications envisage some pumping of water. This reflects a clear priority for such use of renewable energy both in the Fifth Plan and in the thinking of the Délégué Général for Scientific and Technical Research, who will be responsible for the overall direction of this Project.

The list covers a range of renewable energy technologies. Some are relatively simple but will require careful development and demonstration to gain acceptance (e.g. woodburning stoves). Another is relatively simple (windmills) but has been tried in Senegal on a number of occasions without great success. Technical simplifications to a vertical-axis windmill that can be almost entirely produced locally give promise, however, that some major problems may soon be overcome. Biodigestion and solar fish drying are relatively unsophisticated and promising technologies that are still in an experimental stage in Senegal.

The photovoltaic pump, on the other hand, is not complicated at the village level but depends on high technology during manufacture.

For the next several years it is clear that the electricity-generating panels will have to be imported from the United States. Yet recent scientific advances foreshadow the possibility that within twenty years countries like Senegal will be able to manufacture their own photovoltaic panels. A combination of maintenance-free reliability and rapidly falling prices makes photovoltaics a most promising renewable energy candidate.

Senegal is an appropriate location for testing all of the applications listed above. With the exception of its southern extremes, the country is well endowed with sunshine. Winds of sufficient strength and duration to power low speed windmills are found in a coastal region lying to the north of the Cap Vert peninsula (where Dakar is located). The country's cattle population is large, and the confinement in corrals of oxen used for animal traction is beginning to provide easy access to manure supplies in villages where biodigesters might be installed.

What is more, Senegal is receptive to solar energy because of work done at the University of Dakar on thermo-dynamic applications of solar energy by the late Henri Masson. The Institute of Meteorological Physics (I.P.M.) was the site of pioneering developments in thermo-dynamic solar pumps in the 1960's. Further work on the technology led to the installation of four solar pumps at sites northeast of Dakar and to the approval of a joint AID-French project for a 30 kW installation at Bakel on the Senegal River. In the past couple of years it has become apparent to most observers that this technology is more appropriate for large installations of the Bakel variety than it is for small village-level applications. Easier operation and maintenance, less bulk, and lower cost make photovoltaic pumps preferable to thermo-dynamic ones in villages.

The project also intends to contribute to the search for solutions to Senegal's firewood shortage. The seriousness of the current rate of depletion of the country's fuelwood resources is recognized in Government circles and was recently given heavy emphasis in the Club du Sahel/CILSS report on the energy picture in the Sahel.*

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*CILSS/Club du Sahel: Energy in the Development Strategy of the Sahel: Situation, Perspectives, Recommendations. Oct. 1978.

The Project would seek to contribute on three fronts. First, it would attempt to develop a simple, culturally acceptable woodburning stove made with local materials. For a start, a number of models are suggested in the Club/CILLS report and elsewhere. The advantage of such a stove over the traditional use of an open fire is that it ensures better combustion and concentrates heat on the cooking utensil so that a meal could be cooked with as little as one-third the usual amount of firewood. Stove prototypes would be built and tested by a Peace Corps Volunteer under the technical supervision of a combustion/charcoal production expert assigned to the Project. Prototypes that are technically sound and appear to be culturally acceptable would then be introduced and demonstrated at the village level by organizations that have expressed an interest in doing so. These include the Centres d'Expansion Rurale, the Maisons Familiales Rurales and CARITAS Senegal.

A second aspect of the search for solutions to the fuelwood crisis would be continued work on improving traditional charcoal production techniques. A Peace Corps Volunteer currently working on the subject in Ziguinchor in the context of an FAO/UNDP Project has indicated a willingness to return to Senegal after completion of his Volunteer service to direct this part of the Project. The "Casamance method" of production that he has developed, described in Appendix B, may prove capable of increasing charcoal yields from around 20 percent under the traditional method to 30 percent. The importance of such a major improvement to Senegal's fuelwood resources is made clear when one looks at the very high rate of charcoal consumption in the urban areas of Dakar and Thiès.

A third aspect of the recommended approach to the fuelwood crisis is the possibility that Peace Corps Senegal will work out with the Forestry Service and submit to AID a proposal for a village fuelwood production program. The village woodlots would contain approximately 20 hectares of eucalyptus, acacia, neem and other species to yield about 200 steres of wood per hectare after six or seven years. Villagers would prepare, plant and maintain the woodlots with technical support from Peace Corps Volunteers and the Forestry Service. Such a project would complement the project recently submitted to AID/Washington for a 6,000-hectare fuelwood production area in the Bandia Forest near Dakar.

By working on three different aspects of the fuelwood question -- tree growing, charcoal production efficiency and woodburning stoves -- this project will address Senegal's most urgent energy need while at the same time preparing the ground for rural exploitation of sun, wind and biomass.

The Project will be directed by the Délégation Générale à la Recherche Scientifique et Technique (DGRST), which comes under the Prime Minister's Office. This Department was created in 1973 to take responsibility for aiding the Prime Minister to conceive and execute Government policy with regard to scientific and technical research. The bureau within DGRST which has been designated to have responsibility for this Project is the Direction de l'Innovation et du Progres Technologique.

The progression of project activities may be best understood by considering it to have four phases.

Phase One (October 1979 - March 1980)

The first phase will be devoted to R & D work. The project would provide support to the Senegalese research center now being created to coordinate all work on renewable energy matters. The Institute of Meteorological Physics will be transformed into the Center for Study and Research on Renewable Energy (CERER). As the need arises, it will call on other research institutes. For example, in the case of photovoltaic village power supply, new research on optimal combinations of uses would be undertaken in collaboration with the University Institute of Technology (I.U.T.). In the case of wood and charcoal the Polytechnical School at Thiès may be asked to help.

Specifically, the project calls for six months of U.S. technical assistance in the field of photovoltaic applications. A technician from a U.S. research institution such as the NASA Lewis Research Center or the M.I.T. Lincoln Laboratory in Lexington, Massachusetts, would be able to provide the needed expertise. The project will also require three months of technical assistance on development of a biodigester for later installation at one or two test sites.

At the same time, five Senegalese participants would be sent to the U.S. for six months. Three would study photovoltaic applications and two

biodigestion. Study in the U.S. is clearly indicated in the case of photovoltaics since the technology has been pioneered and rapidly developed in the States. Biodigestion could be studied at a U.S. University such as Cornell, where interesting research is going on, but might also be studied in a third world country such as India where biodigesters have been used for a period of time. In cases where the participants do not have the required level of English, an additional three months of language training should be included if necessary. The participants might be junior staff at CERER or another research institute who could be expected to return and work on the applications they will have studied. They could also be advanced students from the University of Dakar or the Polytechnical School at Thiès for whom salaried positions have been reserved. In no case would U.S. Training be given to someone who is not assured of a funded position on his or her return.

The Government of Senegal will also be asked to provide financial support to a few students enrolled at the University or at Thiès to enable them to participate in the applied research to be undertaken in this phase of the project.

While research and training are getting underway, preparations would begin for the survey phase of the project. Twenty village and small town survey sites would already have been identified by DGRST in consultation with other Government agencies before the project began. The criteria for site selection are:

1. Existence of energy needs which could be met by one of the energy technologies,
2. Indications that there is enough sun, wind or collectable biomass to power the devices,
3. Evidence of openness to innovation, of self-help accomplishments, and of dynamism on the part of the villagers,
4. Existence of either traditional or modern institutions at the village level which would facilitate village operation and maintenance of the devices,
5. Sufficient geographic spread to cover the major ecological and ethnic areas of the country.

By meeting the criteria, the sites are apt to be central villages on which a number of neighboring villages depend. Some of these neighboring villages would be included in various parts of the survey so that it will give a more representative picture of the rural energy situation in Senegal.

The list of sites where water pumping devices may be installed in the test phase of the project is already limited by one major consideration. DGRST agrees that an appropriate Senegalese contribution to the project would be boreholes (forages) and/or wells for the sites where solar, wind or biogas driven pumps are to be set up. It is not possible, however, to envisage such installations if they do not already exist or are not contained in the Government's current well-drilling program. It turns out that there are over sixty sites where the Government and/or foreign donors have recently installed or plan to install sturdy "forage-puits". These installations have the advantage of containing a deep borehole to which a renewable energy pump can be installed, complemented by a well from which water may be drawn by hand at those times when the pump is not operating.

Preparations for the surveys to be conducted at these sites will include the recruitment and training of survey personnel. The survey structure will have three levels. It will be conducted under the overall supervision of the DGRST in frequent consultation with a working group of consultants. The latter would be composed of staff of the National School of Applied Economics (ENEA), an American social scientist, a Senegalese economist and staff from CERER. ENEA will concentrate on the content of questionnaires and on the training of survey staff. The school is experienced in rural survey work; in fact, it has trained most of the personnel who administer rural surveys for the Government.

The second layer of survey staff will be found at the regional level. Four teams of supervisory personnel will be based in regional capitals and equipped with vehicles to be used in regular visits to village sites. As will be the case at the site level, each team of two supervisors will to the extent possible consist of a male and a female in order to ensure that the viewpoints and activities of both sexes are reflected in the final survey results.

At the site level, there will be a team of two enumerators per site.

In instances where some means of transportation will be needed to gain coverage of outlying villages, bicycles will be provided to the enumerator team.

Recruitment of enumerators and supervisors will be the responsibility of DGRST assisted by ENEA. The former will request the regional development authorities (SAED, SODEVA, SOMIVAC, SODEFITEX) and the national agricultural research institute (ISRA), which comes under its jurisdiction, to detach qualified survey personnel to the project. To the extent that these organizations cannot provide adequate numbers, DGRST would recruit and hire enumerators on limited contracts. As is commonly the practice in Senegal, individuals would be sought who had attended secondary school through the 10th grade (3eme) but had not gone much further.

The consulting working group will devote time in the first three months of the project to establishing the content of the survey, elaborating the suggested outline found in Appendix F. As much as possible, questionnaires will be tailored to the specific requirements of a site. A large number of socio-economic studies have been undertaken in Senegal in recent years. Many have little direct relevance to an energy program, yet they will be quite useful in drawing up questionnaires for each site.

Recruitment and survey preparation should be completed about half way through the first phase of the project, enabling the training of enumerators and supervisors to get underway at ENEA in about the fourth month. The training program will be conducted by ENEA staff at the school with considerable collaboration on the part of other members of the consulting working group.

Phase Two (April 1980 - December 1980)

There are essentially three objectives for the survey phase of the Project:

1. To obtain accurate information from each site in order to make a decision on whether a renewable energy application should be tested there,
2. To determine which village groups and individuals would be best suited to take responsibility for installations,

3. To obtain baseline data to be used in evaluating the social and economic impact of the installations.

Worth emphasizing at this point is the need to seek meaningful village participation in the project. The Social Soundness Analysis discusses the point in detail; suffice it to say here that the survey period is the time when the villages will demonstrate their willingness to commit themselves or lack thereof. Great care must be taken in eliciting the nature of their participation and it must be a major factor in the final site decision.

The period of data-gathering for the survey would be six months at most, the full duration being reserved for those sites where little will have been known before the arrival of the enumerators. Sites where considerable information is already available, such as a central village with a Maison Familiale, will need to be studied for only about three months. Where there are sites with lower requirements for new information, enumerator teams may be able to cover two sites during the survey phase. This should reduce the costs involved and make supervision somewhat easier.

The fact that there will be twenty survey sites, only eight to ten of which will be chosen for the installation of a major renewable energy device, provides flexibility in making a final selection. Primary considerations in the choice will be:

a. the verified existence of sufficient sunlight, wind or collectable biomass,
b. the demonstrated willingness and capacity of villagers and village-level institutions to participate in the program,
c. the verified existence of energy needs that can be met by a renewable energy device,
d. sufficient spread of the installations to cover the major ecological zones and ethnic groups.

Those survey sites where the village population may have shown scant interest in the program or willingness to make a meaningful contribution would have no follow-up. Other survey sites where these qualities were demonstrated but which were not chosen for a major installation would be

eligible for woodburning stove demonstrations, solar hot-water heaters for dispensary or maternity use, and participation in the Peace Corps proposed village fuelwood program.

In any case, whether the survey site will be chosen for a large installation or for one of the alternatives, the survey will have provided substantial baseline economic and sociological data, against which changes may later be measured.

As the survey progresses, closely monitored by the responsible official at DGRST and the American social scientist, preparations will be underway for the installation of pumps, biodigesters, windmills and other devices in the next phase. As discussed above, applied research and engineering work will have been done on each of the applications from the beginning of the project. As the third phase approaches, each specific application should be in a state of readiness. If for some reason progress has not occurred as expected and technical or engineering problems remain to be solved prior to installation, village installation will have to be delayed.

The project would engage SINAES* to take responsibility for the sequence of actions that lead from the importation or local purchase of components to verification of site readiness to installation and start-up. SINAES was established in 1976 to perform this kind of function for renewable energy devices. It has done so for the solar pumps of the SOFRETES variety, for windmill installations, and for the joint AID-French solar project at Bakel. While there are French shareholders in the company, notably SOFRETES itself and Renault, Senegalese national and private interests are well represented.* The PP team concluded that SINAES was the local organization best equipped to handle the myriad details involved in implanting these new forms of technology in village settings. SINAES would take responsibility for the solar panel installations,

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*Société Industrielle des Applications de l'Energie Solaire, B.P. I277, Dakar.

*Senegal 13%, Electricité du Sénégal 10%, other Senegalese interests 7%.

hot-water heaters, windmills, and biodigesters. CERER, which has been working for some time with solar fish dryers would remain in charge of them. Woodburning stoves would be demonstrated by extension organizations, as previously indicated.

Toward the conclusion of the survey phase, after the first few months worth of data have been collected and analyzed by the consulting working group, choices will need to be made. The working group will be asked to make its recommendations on two crucial matters: (a) the choice of sites for specific installations and (b) the choice of individuals and groups from sites who will be trained to take over responsibility for the renewable energy installations. The final decisions will rest with DGRST, after appropriate consultation with other Government agencies. Once the choices have been made, SINAES will be empowered to make final site preparations and to undertake a training program for the villagers selected to operate and maintain the devices it will install. By the same token, CERER would train villagers on the solar fish dryers. Woodburning stoves, on the other hand, will probably not yet have been demonstrated at village sites and would in any case require little or no formal training.

The survey phase would conclude with a conference bringing together all of the persons involved in the survey. The purpose of such a conference would be to prepare in outline form a synthesis of the results of the survey. Under the supervision of DGRST, the final activity of the American social scientist prior to returning to the U.S. would be drafting a report on the survey.

Phase III (January 1981 - December 1982)

The third phase of the Project is the longest. Activities set in train during the second phase will continue to their logical conclusion. As soon as a definitive choice of sites for different installations has been made, devices that are in readiness can be set up and observation of their impact can begin. The scrutiny of individual sites will be less intense in this phase of the Project, the object being to record significant social and economic changes as they appear and to observe the technical performance of the new technologies. The number of observers will there-

fore be reduced so that each team of two enumerators will cover two sites rather than one. This will ensure continued observation of both male and female participation.

On the technical side, SINAES will undertake a regular schedule of technical site visits, averaging one every three months, to those villages where major installations have been placed. One of the fundamental purposes of the project being the encouragement of local self-sufficiency in operating and maintaining devices, the program of visits should be designed to taper off. At sites where it can taper off rapidly, this will be an encouraging sign that the particular set-up is working. At sites where breakdowns constantly occur and technical visits do not taper off, the combination of technology and local organization will be proving its inappropriateness.

Phase IV (January 1983 - September 1983)

The final phase of the Project will focus on an evaluation of the results obtained from introducing the seven renewable energy technologies under controlled conditions in rural Senegal. Sufficient data should have been obtained from the village surveys and the observation of project impact over a period of two years to permit a conclusive evaluation of the results. DGRST will remain the responsible government agency and direct the evaluation. The exact composition of the evaluation team will be determined by DGRST during the previous phase of the Project. Two of the members would be the two consultants who will have followed the Project from its inception -- the U.S. social scientist and the Senegales economist. Both would be engaged to spend up to 60 working days on the evaluation. CERER and the other scientific research institutes would be represented. Government officials from the Ministry of Planning, the Direction de l'Energie and the Ministry of Rural Development would be logical choices to participate in some fashion. The objective of the exercise would be to determine which technologies and which methods of organizing to exploit them had been proven to be technically, economically and socially sound. Recommendations to the Government of Senegal would be made on the basis of these determinations.

The project would be concluded with the issuance of a final evaluation report in both French and English.

While no additional expenditures are envisaged, favorable determinations and positive recommendations coming out of the evaluation would be the first step in a far wider dissemination of renewable energy technologies in Senegal. Donor countries and such international organizations as UNIDO may then wish to consider participation with the Government of Senegal in a new project. The renewable energy picture can be expected to evolve so rapidly, however, that there is little point in speculating at this time on what additional steps would seem advisable in 1983.

II. Social Soundness Analysis Summary

The Senegal Renewable Energy project can play two important roles in the area of rural development. The first is that of responding to basic needs by providing improved energy sources for the most fundamental tasks. The second important function of the project is that of putting the new technologies into the hands of the villagers for them to manage and maintain, thus creating a situation in which the villagers themselves must organize to integrate the new technological devices into their lives on their own terms. Different technologies will be tried in parts of the country characterized by differences in climate and mode of production as well as in ethnic culture. The purpose of such diversity is to ascertain which devices work best in what circumstances and how different human groups respond to them. This information would help Senegalese authorities decide in future what kinds of devices and what forms of social organization deserve wider promotion.

A basic premise of this project is the necessity for assuring local control of modern technology. Much modern technology introduced into rural areas has failed to be used once the external support system that brought it has left. In many instances mechanical problems developed for which the people were not trained or did not have adequate materials. Nor did they feel that the new device was really theirs and hence that they were responsible for it. In other words, they had not integrated it into their lives. If modern technologies are to be put to service improving rural life, this integration is necessary. Technologies must respond to needs felt and expressed by the peasants, which the villagers

are willing to try new techniques to alleviate. The villagers must be provided with training to maintain the devices in functioning order without much external support. And they must create the social organization necessary to manage the new devices, thereby replacing or modifying whatever social organization assured the accomplishment of the same tasks in the past.

The tasks to be energized initially by the renewable energy devices are those that are the most fundamental. The first priority expressed by everyone concerned with rural development, both officials and villagers, is an adequate and reasonably accessible water supply. Currently, in many areas village wells dry up in April and May at the end of the dry season and people must spend several hours a day fetching water from distant sources. Women fetch water for domestic purposes and men for their animals. The absence of adequate water has a number of consequences which this project should help to remedy. Because of the lack of water, crops can be grown only one part of the year. During the dry season, the rural diet is meager. The presence of improved water pumping devices would allow the planting of gardens, the produce of which could improve local nutrition. Any excess could be sold as a source of income.

Women's activities keep them busy during both the wet and dry seasons. The time that they might have spent in the fields in the wet season tends to be spent in finding water in the dry season. Men, however, have fewer activities in the dry season, being unable to farm, and hence would be able to devote themselves to gardening activities. A major dry season social problem is the rural exodus of young people who, having few constructive activities to occupy them in their villages, leave for the urban

areas to seek employment and excitement. Many do not return, thus contributing both to urban problems by joining the mass of the young unemployables, and to rural impoverishment by depriving their villages of their most dynamic elements. By providing a constant water source, this project could help provide activities for these young people to make village life more attractive.

The second major task to be energized is the preparing of the staple cereals for cooking, currently done by women by hand. The hulling of rice or the hulling and reducing of millet to flour takes women several hours per day. The provision of renewable-energy-powered grinders would free women from this task and give them time for other activities.

A third area in which the project should help to diminish the time and energy spent in a basic task is the gathering of firewood for meal preparation.

Particularly in the densely populated areas, which coincidentally are also the most deforested, gathering wood for cooking daily meals may take several hours. Charcoal is used in the cities, and the Government is encouraging the use of butane gas, but both are too expensive for village budgets. From all indications, women would be pleased to have stoves that would burn wood more efficiently and thus require less fuel.

The introduction of these elements of modern technology into the rural milieu would be done through grassroots development organizations both external and indigeneous. Organizations such as the Maisons Familiales Rurales (MFR) install well-trained young development agents in villages to help the villagers become conscious of how they might like and be able to change their lives. MFR agents then help them acquire the technical and organizational skills necessary to make such changes. Such

structures could help prepare villagers for the introduction of the new technology and then help them to organize to manage it effectively.

As a result of Administrative Reform,[1] four Regions have been divided into rural communities, each with an elected Council having responsibility for deciding upon and implementing rural development projects. These grassroots village-level organizations, which receive technical assistance from rural extension agents based at the Arondissement's (Districts) Centre d'Expansion Rurale, can own property and have a budget for local investment. At some sites the new technology will have a large enough impact on the rural community to permit the participation of the community Council in deciding how it is to be managed. At other sites the decision will remain with the village proper. Both kinds of organizations, those that come from outside and locally organized village groups, serve as the basis for creating new village structures, often along the lines of traditional ones modified to meet new needs. Organization around the renewable energy technologies would not be a foreign concept to most Senegalese villagers.

Thus the technologies introduced would respond to real, felt needs, and would be integrated into the lives of the peasants through participatory grassroots structures. They would serve to lighten the time spent on repetitive tasks by both males and females, and allow them to

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[1] A set of laws voted in 1972 established the Administrative Reform, which has been applied progressively by Regions: Thiés (1972), Sine Saloum (1974), Diourbel (1976) and Casamance (1978). One of the main thrusts of the Reform is to delegate authority over the expenditure of local tax monies to rural community councils. The rural community is delimited as a group of villages within a radius of about 5 km. from a central village which serves economically, socially and historically as a pole for the others. The population of the average rural community is supposed to be 8,000 to 12,000.

spend it more profitably in other ways of which they are already aware. They could grow gardens to improve their nutrition. The profits could go both to maintaining the new installation and to other activities such as a dispensary, a maternity, self-improvement courses in literacy, nutrition, child-care, etc. Many villagers are sensitized to the advantages these installations could have in their lives from examples of which they are aware, and are anxious to have them to help them improve the quality of their lives.

III. TECHNICAL ANALYSIS SUMMARY

The technical feasibility of a renewable energy technology depends on the availability of the energy source and on the properties of the energy conversion device. The needs of rural Senegalese which can reasonably be satisfied by renewable energy sources are listed below in prioritized categories as determined by PP team consultations in Senegal and by reference to appropriate documents.

Energy Needs

Highest Priority: (a) an adequate water supply for human, animal and plant consumption and (b) an adequate and easily available supply of energy for cooking. Of these, improved water supply appears to be most needed at the present time.

Second Priority: Energy for cereal grinding, hulling and shelling (maize) is needed particularly to lighten the labor of women. Fish drying at high temperatures is needed to avoid the large losses incurred by traditional drying methods.

Third Priority: Crop drying, refrigeration, lighting, sanitary hot water, battery charging (flashlights, crop sprayers, radios), communications (educational T.V.), sterilization of water, and desalinization of water were judged to be somewhat less urgently needed. Energy needs are discussed more fully in the Appendix A.

Energy Sources

To meet these needs, renewable energies must, of course, be available in sufficient quantities and at the right locations and times. Competition with other uses, e.g. the use of agricultural products for energy rather than food or fertilizer, must be considered. A brief outline of renewable energy sources in Senegal in rough order of availability is given below. These are determined from meteorological records, from consultations with Senegalese officials and from documents.

1. Direct Solar Energy, being the primary source from which the other renewable energy sources derive, is the most abundant. Insolation

is high throughout most of Senegal but somewhat lower in the south. Its annual maximum coincides with the maximum annual need for water (the highest priority) occuring during the driest and warmest months. Its diurnal maximum, however, conflicts with cooking needs (the second highest priority), occuring at solar noon when cooking is generally not done.

2. Solar Energy via Photosynthesis is not abundant in the north because of lack of water. It is more abundant in the south, primarily in the form of wood. Other forms are cattle dung and agricultural wastes. The wood resource is over-used and decreasing. Tree-planting, conservation, and development of more efficient means of wood utilization could increase energy availability from this source. Cattle dung is concentrated enough to be useful in some places. Peanut shells already provide power for peanut oil plants and electricity for the town of Ziguinchor.

3. Wind Energy is not a large resource. Useful wind speeds exist only along the Atlantic coast well north of The Gambia and probably in the far north. Even there the available wind energy is much less abundant than at higher latitudes.

4. Water Power for village-level use does not exist in Senegal except possibly in the southeast corner.

5. Wave, Tidal, Ocean Thermal, and Geothermal resources are not abundant nor adaptable to small scale conversion.

6. Animal Energy is an abundant resource. It is most applicable to transportation and agricultural employments which are not considered in this project.

7. Human Energy is abundant but considered to lie outside the scope of this program.

Energy Conversion Technologies and Devices

Energy conversion technologies and devices are the links which connect sources to needs. These should be easy to use, have a long life, be easy to maintain and repair, be locally constructable as far as possible, and use local materials where possible. In addition to these technical requirements, they should satisfy, as far as possible, a range of social and economic criteria which are discussed elsewhere. A brief discussion

of these technologies, not in order of importance, is given below.

1. Photovoltaics: Solar energy can be converted directly to electrical energy by means of solar cells. These have long life, are simple to use, provide energy directly in its most useable form (electrical), require little maintenance, and are easy to repair (compared, for example, to a diesel generator set). At present, they are not made in Senegal and their cost is too high. In the furture, most if not all parts can be made in country and the cost should be low (see Appendix B).

2. Flat Plate Collectors: Solar energy can be converted directly to heat at temperatures below 100°C for sanitary hot water and fish and crop drying. This low temperature heat can also be used to drive a thermodynamic engine, as in the SOFRETES water pump, to produce electrical or mechanical energy. The flat plate collector is easy to maintain and has a long life, but only if it is well constructed. The cost is reasonable and it can be made locally, but the glass and metal materials which constitute the most expensive part must be imported. Thermodynamic engines, heat exchangers, pipes, condensers, etc. must be imported, are expensive, require skilled maintenance and are not well suited to small-scale use. Because of the large mass of materials used, glass and metal, the potential for future cost reductions is not as good as for photovolatics for which the mass of materials can be very small.

3. Concentrating Collectors collect heat but at a higher temperature than flate plate collectors. They can be used to cook and to sterilize. They can drive a thermodynamic engine more efficiently because of their higher temperature, in order to produce electrical or mechanical energy. By using less materials they have better potential for cost reduction than flat plate collector systems. However, they require sun-following mechanisms, which make them more complex and susceptible to failure. They also fail to collect a large portion of diffuse solar radiation, which can be significant in Senegal.

4. Anaerobic Digesters (biogas) convert dung and agricultural wastes to a methane-carbon dioxide gas which can be used directly for heating, lighting and drying purposes or to drive an engine to produce electrical or mechanical energy. This technology requires a considerable amount of

labor and care for operation and maintenance. It can be constructed locally and mostly from local materials. Its cost is not low and potential for future cost reductions is not good.

5. Pyrolysis converts wood, agricultural wastes, etc., to combustible char, liquids and gases. Charcoal making is the most commonly employed form of pyrolysis. In the charcoal making process, however, the liquids and gases are mostly wasted. Methods and equipment for improved charcoal making could employ local materials and skills. The costs should be low. On the other hand, collection and use of the liquids and gases require more complex and expensive equipment which has a larger import component (steel for example). Operation and maintenance requirements would also increase. The liquids and gases are not easily convertable to fuels for engines.

6. Fermentation converts photosynthetic materials (wood, sugar cane) to alcohol. Removal of the water to produce high quality fuel is expensive. This conversion technology is thought to be most appropriate for large scale use in wet climates such as in Brazil where gasoline-alcohol fuel mixtures are available for motor vehicles.

The Most Promising Applications

Finally, by considering simultaneously the (a) needs, (b) sources and (c) conversion technologies and devices, we select eight promising combinations. These are then listed with a short discussion of each.

The most promising applications generally correspond to the highest priority needs. However, some second and third priority needs can be satisfied because of the favorable "source" and "technology" situation. Each of these eight applications is discussed more fully in Appendix B.

Photovoltaic Water Pump: The favorable conjuncture of need, source and technology make this a logical choice. The unfavorable present cost situation is expected to be corrected during the next decade. In this application we will attempt to solve the problem of the peripheral costs: reservoirs, fences, installation, experts, etc. Transferring the technology of solar cell manufacture to Senegal should be no more difficult than transferring the technology of oil refining (already done).

Photovoltaic Power Source: In order to utilize the photovoltaic energy supply more fully and to satisfy other needs, we plan installation of a general photovoltaic power source which will supply energy primarily for water pumping, but also for cereal grinding and shelling, and for refrigeration, lighting, battery charging, and educational T.V. as appropriate.

Water Pumping by Windmill: The principal aims of this application are: supplying the highest priority need and solving the problem of maintenance. Windmill techonology is well developed but has been remarkably unsuccessful in the Sahel. We think this to be a problem of social acceptance (no sense of proprietorship), lack of maintenance, high cost and, in some cases, lack of wind.

Fish Drying: Although the need is judged to be of second priority, the situation regarding the technology and the energy source are favorable. The use of expanded concrete for construction and the use of the dryer during only part of the drying process promise to increase the effectiveness of this application. The Government of Senegal has supplied $7,000 for construction of the first model.

Biogas for Water Pumping: Large amounts of cow dung can be collected at watering points. This will be used via anaerobic digestion to produce methane to run the water pump. This is a favorable combination of need, source and technology.

Improved Charcoal Manufacture: The urban poor of Dakar and Thiès depend almost entirely on charcoal for their cooking fuel. Charcoal manufacturing yields can be improved by 50% according to work done by the FAO/UNDP forestry project in Ziguinchor.

Improved Cooking Stoves: Current cooking practice utilizes only 6-12% of the heat from wood combustion. Improved cooking stoves can increase this by a factor of 3 to 5. This is a particularly favorable combination of need and technology and would result in major conservation of a diminishing resource. Construction and materials will be almost 100% Senegalese.

Solar Sanitary Water Heating: Although the need has been judged to be a lower priority, the combination of resource and technology is parti-

cularly favorable.

These eight applications are discussed in more detail in Appendix B.

IV. ENVIRONMENTAL CONCERNS

An initial Environmental Examination has been carried out and submitted to USAID/Senegal. In view of the fact that water pumping will be on a small scale, water will not be impounded and the devices to be utilized will be non-polluting, environmental impacts are all expected to be beneficial initially.

The only concern that may arise is the movement of persons to the vicinity of potable water. The pumps will be sized to suit the populations where they are installed and will all be of small size, so as to minimize population movements.

V PROPOSED BUDGET

1.	Participant training: 5 students	$52,000
2.	U.S. technical assistance:	
	(a) Photovoltaics engineer (6 mos.)	36,000
	(b) Biogas engineer (3 mos.)	21,500
	(c) Social scientist (18 mos.)	150,000
	(d) Charcoal production specialist (18 mos.)	75,000
3.	Vehicles:	
	(a) Utility vechicle for CERER	12,000
	(b) 4 pick-up trucks for survey	35,200
	(c) sedan for social scientist/DGRST	10,000
4.	Vehicle operating expenses	109,000
5.	Commodities:	
	(a) lab equipment for CERER	37,000
	(b) wind measuring equipment for sites	9,500
	(c) bicycles for enumerators	3,000
6.	Components for installations (including shipping to Dakar):	
	(a) photovoltaic pumps (2)	64,000
	(b) photovoltaic power supply (2)	
	Foreign exchange costs	107,000
	Local costs	11,000
	(c) windmills (2)	18,500
	(d) biodigester (1)	
	Foreign exchange costs	30,500
	Local costs	30,000
	(e) solar fish dryer (1)	25,000
	(f) solar hot water heaters	10,000
7.	Charcoal production program	35,000
8.	Woodburning stoves program	21,000

9. R&D costs: support for CERER, other institutes		$ 60,000
10. Books & periodicals for DGRST & CERER		8,000
11. SINAES contract:		255,300
(a) Installation costs (transport to site, site preparation, civil engineering, installation, start-up, verification, training of local personnel, etc.)		
(1) PVC pumps	$16,000	
(2) PVC village units	77,000	
(3) windmills	13,800	
(4) biodigester	60,500	
(5) hot water heaters	5,000	
Total:	$172,300	
(b) Periodic site visits	85,000 (2 years)	
12. Consultants:		
(a) Senegalese economist (245 days)		34,600
(b) U.S. social scientist (150 days)		38,200
13. Training program for survey staff at ENEA		55,000
14. Survey costs: (includes 2-year test phase)		319,900
(a) Office expenses (includes reports)	$102,000	
(b) Enumerator salaries	134,700	
(c) Supervisor salaries	54,600	
(d) Housing costs survey personnel	28,600	
15. Evaluation team expenses		6,000
		$ 1,679,200
rounded to:		1,680,000
20% contingency & inflation:		336,000
Project Total:		$ 2,016,000

VI. IMPLEMENTATION PLAN

The schedule for project implementation is set forth below. The following implementation arrangements would be established for carrying out the project in accordance with the schedule.

Senegalese Arrangements

Responsibility for the project lies with the Délégation Générale à la Recherche Scientifique et Technique (DGRST). This Department is headed by the Délégué Général, who has the rank of a Minister and reports to the Prime Minister. Responsible for coordinating all scientific and technical research, he is empowered to call on other ministries and agencies for their help. The Délégué Général will make all of the major project decisions after prior consultation with other agencies.

The progress of the project will be closely followed by one of the Délégué Général's principal subordinates, the Director of the Bureau of Innovation and Technological Progress. Within the bureau a Senegalese civil servant will direct the project on a day-to-day basis. Fifty to sixty percent of his time will be devoted to project matters. This individual has not yet been chosen but is expected to be one of three new staff members -- a lawyer, and economist, and a polytechnical school graduate -- who will be assigned to the bureau prior to July 1979. A Senegalese sociologist (Boubacar Ly) will be working two days per week in the bureau and can be made available to work on the project along with his American counterpart.

The other Senegalese Government agencies that will be involved in project implementation include the Center for Study and Research on Renewable Energies (CERER) at the University of Dakar, the National School of Applied Economics (ENEA), the Agronomic Research Institute (ISRA), Promotion Humaine, the Rural Expansion Centers (C.E.R.), the national cooperatives agency (ONCAD), the Ministry of the Interior, the Water Resources Department, the Thiès Polytechnical School, the University Institute of Technolody (I.U.T.) and the Faculty of Sciences at the University of Dakar. A dozen Government agencies including some just

mentioned were called to DGRST on December 13, 1978, to consider and comment on a draft outline of the project.

Also included in that meeting was SINAES, the company partly owned by Senegal that works on the installation and start-up of renewable energy devices such as windmills and solar pumps. It is working with AID, for example, on the Bakel solar station project. SINAES would play an important role in this project as well. Neither the university-level scientific research institutes nor DGRST are equipped to manage the logistics of receiving or purchasing and transporting components to village sites, preparing the sites, doing ancillary construction work, and installing the devices. The process of getting material through customs and obtaining the requisite permissions and co-operation from Government agencies in Senegal can be very time-consuming. SINAES does such work now and is ready to build up its capacity to do more in the future.

The project therefore envisages the negotiation of a contract with SINAES under which it would take responsibility for (a) receiving imported components; (b) purchasing other components locally; (c) storing equipment and materials if required; (d) transportation to village sites; (e) preparing sites for installation, including the construction of reservoirs and other ancillary items; (f) installing and starting up the devices; (g) visiting sites regularly after installation and making repairs beyond the capacity of village operators; and (h) conducting a training program for village operators and for survey staff prior to the installation of devices.

AID Arrangements

The PP team considered, but in the interests of economy rejected, the possibility of having an American project manager assigned to work with his Senegalese counterpart at DGRST. Instead, the American social scientist who will be hired on a personal services contract to work on the project and who will spend 18 months in Senegal at the outset, will be asked to monitor project developments and to bring to the attention of AID/Senegal matters that will require its attention. By the end of the

social scientist's initial assignment in Senegal (the same individual will return as a consultant to the project on later occasions), the survey will have been completed and most of the major actions required to implement the project will have been completed or nearly so. The sequence of important actions is set forth in the schedule below.

IMPLEMENTATION SCHEDULE

Event No.	Item	Date
1	Authorization	March 1979
2	Project Agreement signed	June 1979
3	Conditions Precedent for disbursement met	October 1979
4	Order placed for scientific equipment and vehicles	October 1979
5	Recruitment begun for technical assistance personnel (3), U.S. social scientist and Senegalese economist	October 1979
6	Recruitment of Peace Corps Volunteer for woodburning stove program	October 1979
7	Names of project personnel submitted to DGRST; approval obtained	December 1979
8	E.N.E.A. begins work on survey questionnaires and recruits survey personnel	December 1979
9	U.S. social scientist arrives in Senegal	December 1979
10	Training program for survey personnel begun	January 1980
11	Technical assistance personnel (3) arrive in Senegal	January 1980
12	Consulting working group completes drafting of survey questionnaires	January 1980
13	SINAES contract signed	February 1980

14	Order placed for imported components of renewable energy installations	March 1980
15	Survey training program completed	March 1980
16	Phase II (village surveys) begins	April 1980
17	DGRST makes final choice of sites for each type of installation	September 1980
18	Village operators chosen at each site	October 1980
19	Installations begun where possible	November 1980
20	Village survey ends; conference held to summarize results	December 1980
21	Village operators and survey personnel trained by SINAES	December 1980
22	Phase III (village tests) begun	January 1981
23	Village installations completed	February 1981
24	Report on results of village surveys issued	March 1981
25	U.S. social scientist and charcoal production expert return to U.S. on completion of PSC's	July 1981
26	Social Scientist returns for 45 days as consultant to the Project	Mar/Apr 1982
27	DGRST selects evaluation team	November 1982
28	Social scientist returns for second visit	Dec 1982/Jan 1983
29	Phase III ends	December 1982
30	Phase IV (evaluation begins)	January 1983
31	Evaluation report issued	October 1983
32	Project ends	October 1983

APPENDIX A

ENERGY SOURCES AND USES IN SENEGAL

1. National Energy Picture

The striking aspects of the energy picture in Senegal are three in number. First, the country is virtually without fossil fuel reserves and is therefore obliged to import oil to run its phosphate mines and growing industrial sector. Second, electrical energy consumption is overwhelmingly concentrated in or near the Cap Vert peninsula. Third, Senegal still relies heavily on non-commercial sources of energy -- principally fuelwood -- since some 80 percent of the population lives in rural areas where electricity is neither available now nor likely to become available in the foreseeable future. The CILSS/Club du Sahel study of energy in the Sahel, referred to earlier in this paper, puts at 60 percent the share of wood in Senegal's use of energy. Granted, this is less than the 93-94 percent share found in Mali and Upper Volta, but it is still significant. It is the more so since, as the authors of the CILSS/Club study take pains to point out, fuelwood is a rapidly diminishing and threatened resource.

Senegal is caught between the need to import increasingly larger amounts of increasingly expensive oil for the modern sector and the danger that the rural sector's main source of energy -- aside from human and animal metabolic power -- will become increasingly scarce. President Senghor remarked to Senegal's Economic and Social Council in March 1978 that with the era of cheap energy over, the country needed to "promote the use of goods freely made available by nature: wind and especially sunshine."

These renewable energy sources are unlikely to do much to solve the energy problems of the industrial and mining sector. Solar hot water heaters in urban centers would save quantities of energy if generally substituted for electrical heaters. Solar air conditioning is also feasible and promising. In both cases, however, the use of solar devices will serve only to lower to some degree the rate of increase of consumption of commercially produced energy in the modern sector. A

national energy policy, toward which the Prime Minister's office is beginning to work, will probably be required before there is any appreciable substitution of solar hot water heaters and air conditioners for the wasteful electrical devices that are now routinely installed.

In the rural sector, the energy picture is clearly different. The fossil-fuel motors, engines and generators that have gradually spread in recent years will probably not multiply as they once might have been expected to do. The cost of operation has increased sharply. Diesel fuel is now 75 CFA (35¢) per liter and will have to go higher soon, in the wake of the Iranian shock,* unless the government decides to hold the price down artificially. In a relatively short period of time there has come into being a climate that is receptive to seeking renewable energy solutions to the energy needs of rural areas. There is a hope too that renewable energy devices can be developed that are at once efficient, reliable and appropriate to the rural milieu. The former head of DGRST, now Minister of Rural Development, wrote recently that the objective of renewable energy research is "to show that with relatively unsophisticated techniques and modest means the standard of living of the disadvantaged villages of the Sahel can be raised, and they can obtain energy independence through a judicious combination of the three types of 'soft' energy."

Before turning to the question of whether renewable energy sources are available in sufficient quantity, a few figures will illustrate the current situation with regard to imports of fossil fuels and their use; and a few words will be added on what is known about non-commercial sources of energy.

Oil's share of Senegal's import bill rose from less than seven percent in 1973 to more than 16 percent in 1976. The sharp rise in the cost of imported oil is shown graphically in Figure A-1. National consumption of petroleum products, most of which are refined at the M'Bao refinery,**

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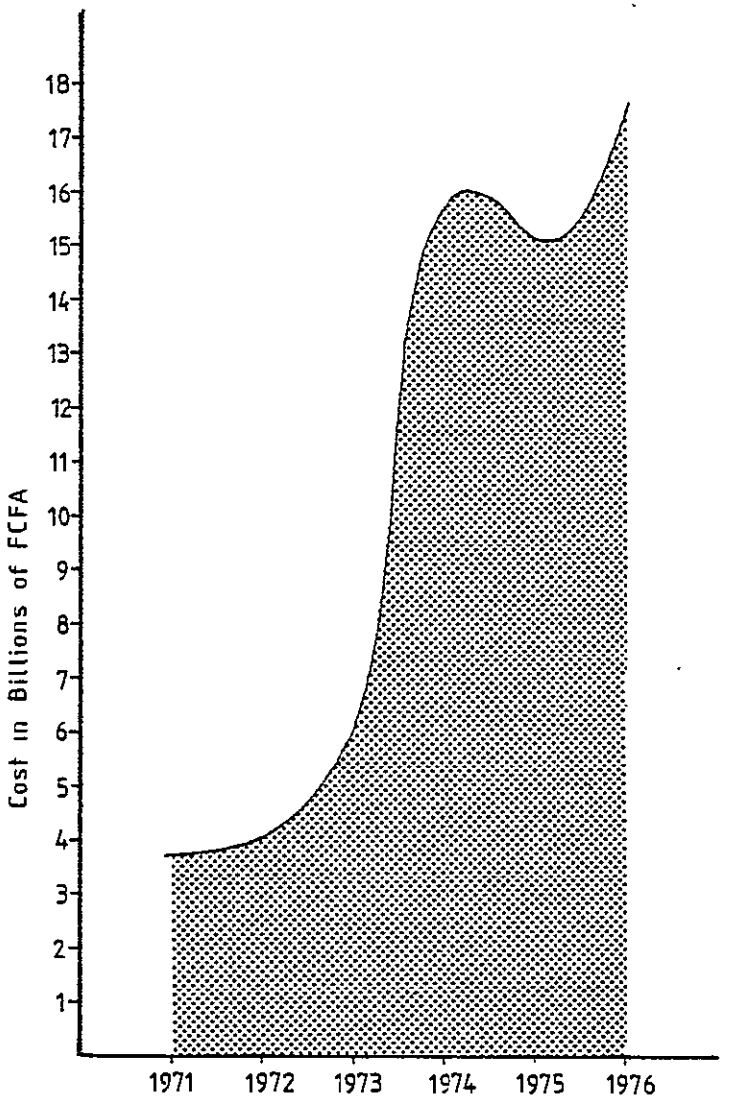
*In 1976 a joint Iranian-Senegalese company was created, IRANSEN, which was to create a new refinery at Cayar capable of refining 1.5 million tons of Iranian crude per year. How recent events in Iran have affected this venture is not known.

**The M'Bao refinery, run by the Société Africaine de Raffinage, has a capacity of some 850,000 MT. It provides petroleum products to southern Mauritania and western Mali, as well as to the national market.

FIGURE A-1 Cost of Oil Imports for Senegal



SOURCE: CILSS/Club du Sahel, Energy in the Development Strategy of the Sahel, p. 24.

came to approximately 566,300 metric tons (MT) in 1977. Half of this amount was in the form of fuel oil to generate electricity, and another quarter went as diesel fuel, also used in electricity generation. Table A-1 gives a more complete picture.

TABLE A-1. SENEGAL's CONSUMPTION OF PETROLEUM PRODUCTS IN 1977

	Quantity (MT)	Percent
Fuel oil	284,000	50
Diesel fuel	137,800	24
Gasoline	121,400	22
Kerosene	18,000	3
Gas	5,100	1
	566,300	100

SOURCE: CILSS/Club du Sahel, op. cit., p. 21.

NOTE: As the CILSS/Club study notes, different sources provide different figures. Africa magazine, for example, citing the Comité Monitaire de la Zone Franc, uses 696,000 MT in 1973 and 722,000 MT in 1975 for Senegal's consumption. (Jan. 1979 issue, p. 36). Other sources are equally at variance.

The consumption of electricity is heavily concentrated in the west-central portion of the country with the main focus, as one might expect, on Dakar. A 90 KVA high-voltage line leads from the power plants at Bel Air and Cap des Biches, located just east of Dakar on the Cap Vert peninsula, to Thiès and from Thiès to the Taiba mines. Smaller 30 KVA lines stretch north from Thiès to St. Louis on the one hand and make a triangular circuit between Thiès, Diourbel and Kaolack on the other. Towns in the rest of the country must rely on individual power plants.*

*The 21 secondary power stations are at: Bakel, Bignona, Dagana, Dahra, Diakhao, Foundiougne, Goudiry, Kaffrine, Kédougou, Kolda, Linguère, Matam, N'Doffane, Nioro du Rip, Oussouye, Podor, Richard Toll, Sedhiou, Tambacounda, Velingara and Ziguinchor.

In most cases, these stations make use of diesel generators. Ziguinchor, which uses a combination of peanut shells and fuel oil, is an exception. Electrical consumption by the so-called secondary centers is dwarfed in comparison with that of the cities of the Cap Vert grid. In the first six months of 1978 the 21 secondary centers consumed only 3.6 GWh of electricity while consumers on the grid used 72 times as much, 260.1 GWh.

SOFRELEC, a French firm, recently did a study preparatory to creating a master plan for the production and distribution of electricity in Senegal. The final report (1) noted that consumption of electricity is being concentrated more and more heavily in the Cap Vert peninsula. It concluded that even by 1990 there would be no justification for attaching any of the secondary centers to the Cap Vert grid, with Richard Toll as the one possible exception. One of the report's recommendations was that Senegal should proceed along the path of decentralizing its generating capacity. This may in part have prompted the position taken by the Fifth Development Plan (1977-81) that solar power stations should begin to replace the least viable secondary plants. As explained more fully in section 3 of this Appendix, France is taking an experimental step in this direction by financing a 23 kW thermo-dynamic solar station at Diakhao.

The SOFRELEC report comes to the conclusion that consumption of electrical energy will increase at the rate of about seven percent per year until 1990. It estimated future demand by doing a multiple regression analysis with eight variables, including population, GDP, value added by sectors, and the consumer price index. The mid-range projection was:

1980	543 GWh
1985	771 GWh
1990	1,169 GWh

Alternative projections were made by establishing trend lines on the basis of an analysis of actual demand in recent years. The results were higher in the mid-term, lower over the long term:

1980	630 GWh
1985	844 GWh
1990	1,080 GWh

In reality, the latter method was a better predictor of the near term, since actual consumption in 1977, two years after the SOFRELEC report was issued, was already higher than the multiple-regression projection for 1980. Actual consumption in selected recent years was:

1963	201 GWh
1970	330 GWh
1974	405 GWh
1977	527 GWh

A word needs to be added about consumption of fuelwood, charcoal and crop residues (e.g. millet stalks) for fuel. Very little is in fact known about actual consumption in the rural areas of Senegal. The CILSS/Club report uses for wood consumption in the Sahel the figure of 0.5 to 1 cubic meter per person per year. Although Keith Openshaw did a wood consumption study in the Gambia that is often cited in the literature, unpublished as it may be, and Elizabeth Ernst studied fuel consumption among rural families in Upper Volta, there has been no research specifically on Senegal that has come to the attention of the PP team. D.E. Earl (2) cautions that there is often wide variation in per capita consumption from village to village and that studies in Nepal and Tanzania have shown that actual consumption of fuelwood is far in excess of what is recorded as having been removed from the forest. He therefore feels that consumption surveys are necessary to determine the amounts of fuelwood and charcoal that are actually consumed. This project proposes to focus heavily on the use of non-commercial fuels, including millet stalks, animal dung and other forms, in the villages that are chosen for surveys in the second phase of the project.

References:

[1]République du Sénégal, Ministère du Développement Industriel et de l'Environment. Etude d'un Plan Directeur du Développement des Moyens de Production et de Transport d'Electricité en République du Sénégal: Rapport Definitif, avril 1975. Prepared by SOFRELEC, Paris.

[2]Earl, D.E. Forest Energy and Economic Development. Oxford, Clarendon Press, 1975.

2. Renewable Energy Resources of Senegal

All of the major renewable energy resources derive from the sun. Exceptions are geothermal energy, renewable only over a long time span, and tidal energy. Solar radiation itself (insolation) is the most abundant resource. Insolation is converted by natural means to wind, hydro, wave, ocean thermal gradient, and photosynthetic energy forms. For village use in Senegal insolation and photosynthesis (primarily in the form of wood) are the most important. Wind is of some importance along the seacoast.

a. Insolation

The solar energy resource in Senegal is reasonably large. However, with the exception of Dakar, it is not quantitatively known. A few measurements of sunshine duration, in hours per day, have been made in cities other than Dakar. Good measurements of sunshine duration and sunshine intensity appear to have been made only in Dakar.

Sunshine duration is measured with the Campbell-Stokes heliograph. This is a device which burns a hole in a strip of paper when the sun shines. It is not an accurate nor a very useful measurement; but it is inexpensive and simple. The intensity of solar radiation is measured with a pyranometer. It is usually called "insolation" and is measured in units of energy falling on a given horizontal area in a given time. At the Institute of Meteorological Physics (IPM) it is measured in cal/cm^2 hour and can be averaged over days, months or years. A unit of measurement that is more convenient for work with photovoltaic converters is watts/m^2 (or kWh/m^2 taken for time intervals of hours, days, months or years).* The pyranometer can measure total (or global) insolation, which is composed of the radiation coming directly from the sun (direct insolation) plus the radiation coming indirectly from the sun (diffuse insolation). The

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*To convert cal/cm^2 to kWh/m^2 multiply by 0.0116, e.g. 500 cal/cm^{2}day = 5.81 kWh/m^{2}day.

diffuse insolation is that radiation from the sun which is scattered by the air itself and by dust or water in the air. In the Sahel diffuse insolation is large. It is caused by water in the air during the rainy season and dust in the air during the dry season. The pyranometer can also be used to measure diffuse insolation and, by subtraction from total insolation, direct insolation. These are the useful quantitative measurements that are needed.

Sunshine duration measurements are made by ASECNA (Agence pour la Sécurité de la Navigation Aérienne en Afrique) at the "Stations Synoptiques." These are shown in Table A-2.

TABLE A-2. "STATIONS SYNOPTIQUES" SHOWING HOURS OF SUNSHINE PER YEAR AS AVERAGED OVER THE YEARS 1941 TO 1970

Station	Hours/Year
St. Louis	3011
Podor	---
Linguère	---
Matam	---
Dakar-Yoff	3066
Diourbel	---
Kaolack	---
Tambacounda	2664
Ziguinchor	2665
Kolda	---
Kédougou	---

The data are collected and stored at the Meteorological Service at the Dakar-Yoff airport. The PP team was able to obtain data for only four stations, as shown in Table A-2. These data show that the sunshine duration in the south of Senegal is about 13 percent less than in the north.

Total insolation is measured at the stations shown below. These stations are part of the AGRHYMET network under the "Projet du Réseau Radiométrique dans le Sahel" which is executed by the World Meteorological Organization with headquarters in Niamey, Niger.

Station	Notes
Dakar-IPM	Records kept at IPM
Bambey	Records kept at the agricultural station, Bambey
Ziguinchor	Records sent to Meteorological Service in Dakar-Yoff
Tambacounda	Records sent to Meteorological Service in Dakar-Yoff
Kédougou	Records sent to Meteorological Service in Dakar-Yoff
Louga	Records sent to Meteorological Service in Dakar-Yoff
Guede	Under OMVS (Organization pour la Mise en Valeur du Fleuve Sénégal)

The records, except as noted above, are sent to the Meteorological Service at the Dakar-Yoff airport. The PP team checked the data at the Meteorological Service and found that there are data from Tambacounda and Ziguinchor but none from the other stations. Evidently the data from Kédougou and Louga which are supposed to be sent there have not yet started to arrive. The team could not discover where the data from Guede is to be kept. Furthermore, the calibration of the pyranometers at Tambacounda and Ziguinchor was said to be faulty. Inspection of the Ziguinchor records shows insolation values averaging less than 200 cal/cm^{2}day during November. This is much too low (it should be at least 400 cal/cm^2 day), and one must conclude that the calibration is indeed faulty. Therefore the only good insolation measurements found were those for Dakar-IPM.

In Table A-3, average hourly insolation measurements for Dakar are shown. These are useful for calculating the hourly performance of a solar device such as a photovoltaic pump or a fish dryer. Table A-4 shows the daily total insolation averaged over ten years at Dakar-IPM. These data show that the insolation is greatest in the driest months, which fortunately coincide with the period of maximum water pumping requirements. The average for May is 605 cal/cm^{2}day. This compares to nearly 750 cal/cm^{2}day for the southwest deserts in the U.S. Values approaching 700 cal/cm^{2}day can probably be expected for northern, interior points in Senegal. From the sunshine duration data of Table A-2, insolation in southern Senegal

TABLE A-3

TOTAL INSOLATION AS A FUNCTION OF TIME OF DAY AVERAGED OVER THE MONTHS OF 1967, 68, 69 AT DAKAR-IPM

(The values are in cal/cm^{2}hour.)

Month	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.	noon	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.	6 p.m.	7 p.m.
Jan.	1.63	12.31	28.05	44.07	54.91	62.04	62.77	57.49	48.67	34.53	18.53	4.65	0
Feb.	2.04	16.94	34.20	51.42	65.46	73.19	71.70	68.22	59.07	43.87	25.08	7.69	0.22
Mar.	5.80	24.15	45.97	65.10	79.20	87.84	88.89	82.16	69.83	51.63	30.04	9.75	0.31
Apr.	10.18	29.21	50.22	66.75	77.54	84.86	85.72	79.55	66.90	48.55	27.98	9.99	0.50
May	12.42	30.13	49.55	64.50	76.04	81.52	81.23	75.86	61.29	46.79	28.26	10.40	1.46
June	11.16	27.84	44.74	60.29	72.03	76.69	77.35	71.64	60.35	44.11	28.48	12.09	2.15
July	8.51	22.95	36.61	52.27	60.29	64.07	63.65	62.69	57.20	44.73	28.04	13.09	2.49
Aug.	7.31	20.49	35.06	47.96	60.47	61.82	64.71	59.12	50.04	33.49	22.04	8.99	1.64
Sept.	7.40	20.38	36.33	49.46	54.36	59.35	59.05	56.63	49.43	36.47	20.98	6.94	0.54
Oct.	6.68	21.55	36.91	49.82	61.41	68.99	65.99	60.13	47.54	34.24	16.20	2.83	0.08
Nov.	5.56	21.30	39.01	53.23	61.69	66.08	62.54	57.58	44.92	29.41	13.02	1.84	0
Dec.	3.25	15.71	32.72	47.51	57.82	63.85	62.49	55.94	44.92	29.29	13.42	2.13	0

TABLE A-4

DAILY TOTAL INSOLATION, IN CAL/CM^{2}DAY, AVERAGED OVER THE MONTHS FOR THE YEARS 1967 THROUGH 1976 AT DAKAR-IPM

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1967	410.5	498.4	596.1	555.3	598.6	538.0	484.0	443.8	416.4	451.4	413.2	438.5
1968	426.6	506.2	649.5	646.9	656.6	650.7	529.8	509.5	513.3	496.3	501.5	417.7
1969	453.3	551.0	659.4	640.8	617.2	587.5	479.4	441.5	474.3	475.3	498.9	417.4
1970	529.6	496.8	655.5	591.9	570.6	560.7	512.8	426.2	455.3	485.3	421.2	385.3
1971	467.0	523.5	559.2	589.7	604.1	563.7	498.4	409.0	485.9	483.6	434.0	417.6
1972	419.2	519.2	536.0	587.4	602.6	551.1	544.3	550.5	--	--	--	--
1973	--	--	614.5	585.5	542.3	483.4	472.2	430.8	491.3	488.3	416.4	465.0
1974	490.6	531.7	581.9	619.6	607.7	546.3	474.5	487.4	475.1	522.8	443.8	370.3
1975	435.0	559.5	594.6	608.4	629.0	555.8	414.5	426.7	412.8	478.7	450.8	431.7
1976	423.4	525.3	558.0	597.4	623.1	582.9	483.8	476.4	426.1	490.1	448.0	384.4
AVERAGE	450.6	522.4	600.5	602.3	605.2	561.4	489.4	460.2	461.2	485.8	447.5	414.2
	averaged over 9 years		averaged over 10 years						averaged over 9 years			

TABLE A-5

RATIO OF DIFFUSE TO TOTAL INSOLATION MEASURED ON THE HORIZONTAL FOR DAKAR

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT	OCT.	NOV.	DEC.
1967	.317	.288	.250	.208	.356	.386	.404	.419	.398	.412	.290	.225
1968	.222	.207	.209	.225	.265	.315	.406	.416	.373	.309	.236	.318
1969	.274	.232	.178	.250	.296	.326	.466	.445	.416	.292	.261	.284
1970	.162	.296	.214	.347	.386	.378	.426	.545	.430	.315	.327	.359
1971	.223	.237	.286	.302	.270	.404	.472	.536	.419	.340	.328	.290
1972	.349	.324	.283	.289	.346	.403	.436	.393	--	--	--	--
1973	--	--	.292	.296	.437	.485	.506	.483	--	--	--	--
AVERAGE	.258	.249	.245	.274	.337	.385	.445	.462	.407	.334	.288	.295
ANNUAL AVERAGE	.332											

SOURCE: Brace Research Institute

could be expected to be about 13% less than at Dakar. Thus one could guess that the total insolation values for interior points in Senegal may be as follows for the month of May.

North Central	700 cal/cm^{2}day
Middle Central	625 cal/cm^{2}day
South Central	550 cal/cm^{2}day

It is obvious that more reliable measurements must be obtained since the insolation could vary about 25% throughout Senegal. That is, other things being equal, a photovoltaic pump might have to be 25% larger in Tambacounda than in Podor.

The ratio of diffuse to direct insolation has also been measured at Dakar IPM. These measurements are shown in Table A-5 for the years 1967-1973. Note that concentrating collection systems, which reject diffuse radiation in proportion to their concentration ratio, could lose up to 50% of total insolation during the rainy season and up to 30% during the late dry season when power requirements are at their maximum. This must be taken into account when designing a concentrating solar system.

b. Wind

The wind energy resource in Senegal is not large. Useful wind speeds appear to be limited to a narrow coastal strip between Dakar and St. Louis.

Wind speed measurements are made by the ASECNA "Stations Synoptiques" listed in Table A-6. The wind speeds given in this table are averages taken from a summary entitled "Le Climat du Sénégal" put out by the Service Météorologique. The years over which the averages are taken were not stated. The measurements were taken at a height of 10 meters. This is a reasonable height for a windmill. Although wind speed increases significantly above 10 meters, the larger costs of higher windmill towers may not be justified.

Since it is generally considered that windmills are not economically viable in regions with wind speeds below 10 mph (4.5 meters/sec.), one sees immediately that Dakar-Yoff is the only location in Senegal where one

TABLE A-6

AVERAGE WIND SPEEDS FROM THE SERVICE METEOROLOGIQUE AT AN ALTITUDE OF 10 METERS

	MONTH												
Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Dakar-Yoff	6.9	7.1	7.4	7.7	6.3	5.7	5.3	4.8	4.7	4.7	6.4	7.0	6.2
Diourbel	2.0	2.6	3.0	3.1	2.7	2.3	2.1	1.5	1.3	1.2	1.0	1.7	2.0
Kaolack	3.5	4.1	3.7	3.7	3.7	3.1	2.7	2.5	2.3	1.8	2.1	2.6	3.0
Kolda	0.3	0.4	0.5	0.4	0.4	0.3	0.2	0.2	0.0	0.0	0.1	0.3	0.3
Linguere	2.6	2.8	2.9	2.7	2.7	2.6	2.6	1.9	1.8	1.7	1.9	2.5	2.4
Matam	1.7	1.1	1.3	1.3	2.1	2.4	2.5	1.7	1.7	1.0	0.3	0.9	1.5
Podor	2.4	2.4	2.3	2.5	2.8	3.3	3.5	2.2	2.5	2.0	1.5	2.1	2.5
St.-Louis	4.3	4.3	4.5	4.7	3.9	4.0	4.2	3.5	3.2	3.1	3.3	3.8	3.9
Tambacounda	2.1	2.1	1.9	1.7	2.3	2.2	2.1	1.8	1.2	1.1	1.1	1.9	1.8
Thies	3.5	4.0	4.3	4.5	3.4	2.5	2.5	1.6	1.7	1.3	1.7	2.1	2.8
Ziguinchor	1.9	2.6	2.9	3.3	3.8	2.9	2.6	2.5	1.9	1.3	1.3	1.6	2.4

(in meters per second)

would be assured of economical windmill operation. A narrow coastal strip between Dakar and St. Louis appears to be marginally economical when one considers that higer than average winds occur in the spring when water pumping requirements are at their maximum.

The average wind speeds do not tell the whole story. The distribution of wind speeds is more important. This is illustrated in Figure B-4, Appendix B. Wind distributions were measured at the Centre Experimental des Eoliennes de Louga for the year 1963 (1). The raw data from which wind distributions can be derived are also contained in the ASECNA records at the meteorological service at Dakar-Yoff. These data appear to exist for all of the AGRHYMET stations listed above.

The distribution for the 15 meter height at Louga, as shown in Figure B-4, indicates that wind power at Louga may be viable. However, these measurements may be too high as shown by a comparison with the ASECNA averages. This comparison is made in Table A-7. The comparison had to be made for different times and different heights since data corresponding in height and time were not found. Comparisons for other months show that the "Centre Experimental" measurements are always higher, sometimes by a factor of two. This leads one to suspect that the "Centre Experimental" data may be too high and that windmills are not viable in the Louga area.

TABLE A-7. COMPARISON OF AVERAGE WIND SPEEDS AT LOUGA MEASURED BY ASECNA AND BY THE CENTRE EXPERIMENTAL DES EOLIENNES DE LOUGA

	January	April
ASECNA averages for 1970-1972 at 1800 hours at a height of 10 meters	2.7	2.7
"Centre Experimental" averages for 1963 at a height of 15 meters	3.3	5.5

It has also been thought that the far north of Senegal may be good windmill territory. However, the average annual wind speed for Podor, the northernmost point in Senegal, is only 2.5 m/s and the highest average monthly speed is 3.3 m/s in June (see Table A-6). There is thus no good evidence to show that the north is a good wind power area.

Inspection of the ASECNA records at Dakar-Yoff shows that the wind along the coast increases to a maximum in the afternoon. This is the diurnal sea breeze caused by daily heating of air over the land while the air over the sea remains at a lower temperature. This, along with the wind records on the coast at Dakar and St. Louis, suggests that wind speeds decrease rapidly as the distance from the ocean increases. Therefore one would expect to find good windmill territory only near the ocean. Consequently, windmills installed under this project should be confined to the Dakar-St. Louis coastal strip. It is strongly recommended that wind speeds be measured at the proposed location and height for a full year before deciding to make an installation.

c. Wood

The wood resource is large but, as pointed out often and emphatically, it is being depleted at an alarming rate. Reforestation programs fifty times larger than those presently planned have been recommended (2). The proposed USAID Firewood Production Project is an important step in this direction. At the same time, more efficient use of the resource through improved wood burning and charcoal making, as proposed for this project, could significantly increase the amount of energy available from wood.

d. Cow Dung

The cow dung resource is large enough in some regions to constitute a useful energy resource. The dung produced by one cow can supply a little more than 1 kWh/day of energy via biodigestion. However, this dung can be widely scattered and difficult to collect. As scattered on a field it is also a useful fertilizer. When used alternatively to produce energy via biodigestion, dung still retains most of its fertilization value but the

labor of collecting the dung and distributing the sludge may make this an unattractive procedure. There are locations, however, where dung is concentrated and not used as fertilizer. Important cattle watering points are an example. There are also locations where draft animals or cattle are confined at night, concentrating the supply of dung. Confinement of draft animals is found, for example, in the Terres Neuves villages south of Koumpentoum and at the Koumbidia experimental unit. The OFADEC project at Bantantinti is seeking funding for the establishment of a cattle herd of at least a thousand head that would also be sufficiently confined to facilitate dung collection and use. The village surveys of Phase II would help determine whether other instances of like nature occur.

e. Agricultural Wastes

Peanut shells, millet stalks, corn cobs, etc. are good energy resources. Peanut shells already produce power for peanut oil plants and, for example, the city of Ziguinchor. Corn cobs, a small resource, are easily used as a cooking fuel. However, straw, stalks, shells, etc. do not have good burning qualities for cooking. Furthermore, burning them directly for cooking or via pyrolysis for heat or electricity production competes with their utility as a fertilizer and soil conditioners. Energy extraction via biodigestion does not compete in this fashion but requires mixing of the waste products with cow dung, the latter supplying the necessary bacteria.

f. Energy Farming

The photosynthetic route from solar radiation to useful energy can take the form of farms whose biomass output is dedicated to energy production. The techniques that could be used would include fermentation to produce alcohol, biodigestion to produce methane, pyrolysis to produce chars, oils and gases, and direct burning. However, energy farming usually competes directly for land and water resources with food production. In Senegal land and water are scarce resources. Nevertheless,

some good energy farming possibilities may exist in southern Senegal where water is more abundant.

g. Small Hydro, Wave, Tidal, Ocean Thermal, Geothermal Energy

These are either small resources or not adaptable to village size exploitation.

References:

[1]Bremond, R. "Rapport d'Interpretation des Résultats Obtenus au Centre Experimental des Eoliennes de Louga (Sénégal)." Diffusé par le Comité Inter-Africain d'Etudes Hydrauliques.

[2]CILSS/Club du Sahel. op. cit.

3. Rural Energy Needs in Senegal

Rural areas require energy primarily for cooking and drawing water. Other needs are beginning to be felt, but these two clearly dominate. This section will discuss water pumping first and then look at other needs for village-level energy. Discussion of fuelwood and charcoal, the primary cooking fuels, is left to the Technical Appendix.

a. Rural Water Supply

The life of rural Senegal is characterized by the heavy dependence of the farming system on climatic conditions and by the undiversified nature of an agriculture based on peanuts and millet. The agricultural sector, which employs 80 percent of the active population, produces only one quarter of the GDP. In this context, a rainfall deficit or a delay in the arrival of the monsoon rains results in an appreciable drop in agricultural production and a compression of rural economic activity.

The 1968-72 drought, for example, caused a 30 percent drop in value added in the agricultural sector. The consequences included: increased underemployment, the lowering of already weak purchasing power in the rural sector and heavier rural exodus.

In 1977 the late arrival of the rains resulted in large deficits in agricultural production: 45 percent for peanuts, 40 percent for millet, 45 percent for rice and 27 percent for cotton. The food grain deficit for the country reached the level of 180,000 metric tons.

These examples illustrate the importance of the availability of water for the Senegalese economy. The country's development is fundamentally tied to the need to obtain adequate supplies of water for human and animal consumption and for crop production. The period of the Fourth Development Plan, which ended in mid-1977, witnessed an investment of five billion CFA francs (over $23 million at current exchange rates)* in 10 boreholes, 55 borehole/wells, and 550 wells. The 1977-81 (Fifth) Plan, projects investment of seven billion CFA francs (over $32 million) in rural water resources projects.

Nonetheless, despite this considerable effort, the problems of rural water supply are far from resolved. The need to reduce the drudgery of the rural population and reduce the amount of time spent by villagers in seeking water has not been squarely faced. Less than eight percent of the investment planned for rural water supply is earmarked for equipping water points with pumps.

An important aspect of the village water supply question is the potential for expanded market gardening. Production reached the neighborhood of 100,000 tons in 1975-76 but then receeded to about 90,000 tons in 1977-78 as a result of the late rains. Two private firms engaged in large scale commercial production with permanent irrigation (BUD Senegal and ASSEPAS) have produced and exported vegetables in quantity, but their production costs are high and their methods are not a solution for rural Senegalese.

It happens that the period of least village activity corresponds with the time when solar insolation is highest and village gardens, if adequately watered, can be brought to peak production. Village consumption of garden produce adds nutritive value to the local diet and can provide additional income at the same time, provided market outlets can be found.

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*An exchange rate of 215 CFA = $1 is used in this paper.

b. Crop and Fish Drying

It is often the case, however, that village gardens in a given part of Senegal are planted at roughly the same time. Since there are no preservation facilities, this causes produce to flood small local markets all at once. Cold storage or drying of garden produce would have the double advantage of keeping prices at a reasonable level and of extending the period during which the rural population can improve the nutritive quality of its diet. Crop drying needs are not restricted to fruits and vegetables. Grain crops with shorter maturities may be harvested before the end of the rainy season in Senegal and thus require drying. This is true, for example, of new varieties of rice that have been introduced at a new experimental unit of the Senegal Agricultural Research Institute (ISRA) located next to Bounkiling in the Casamance Region. It is also true of the 90-day varieties of millet that are being introduced because they can mature in a shortened rainy season. When the rains continue, however, these varieties are harmed.

Another rural product that does not preserve well is fish. Senegal is an important producer of fish, using both industrial and traditional methods. The traditional catch is large and is the result of the labor of almost 50,000 fishermen. A comparison of activities in both industrial and traditional sections of the sub-sector are shown in Table A-8.

The bulk of the traditional catch is landed on the "Grande Côte" north of Dakar (Kayar and M'boro in particular) and on the "Petite Côte" south of Dakar (Joal and M'bour). St. Louis has the greatest concentration of fisher folk, but the fishing season there lasts only about three months, June through August. Migration southward to other fishing grounds follows. Most end up on the Petite Côte, where there is year-round fishing of all kinds. The Grande Côte around Kayar has a season from December through May.

Major markets for fish are found in Dakar, Thiès and St. Louis. In these three urban centers some 72 percent of the marketed catch was sold in 1976. A portion of the catch is exported, either as fresh or as dried fish. In 1975 the value of the exported catch was 3,800 million CFA ($17.7 million) or seven percent of export receipts. There is a large and

TABLE A-8. TRADITIONAL AND INDUSTRIAL FISH PRODUCTION IN SENEGAL, 1974-76

A. Traditional

	1974	1975	1976
Number of fishermen	23,754	46,586	49,000
Number of pirogues	6,442	6,041	6,100
Percentage motorized	65%	67%	67%
Total catch (tons)	262,820	279,110	276,650
Value of catch (million CFA)	14,921	17,381	18,844

B. Industrial

	1974	1975	1976
Number of vessels	144	143	130
Total catch (tons)	84,225	74,168	74,211
Value of catch (million CFA)	6,858	5,765	6,209

well organized women's fish cooperative in Joal that grosses some 17 million CFA ($79,000) a year and exports fish to Ghana and Nigeria.

It is generally recognized that there is considerable loss of fish through infestation by insects during the traditional drying process on racks in the sun. As explained in the technical analysis (Appendix B.4), higher temperatures are required to kill the insects and prevent as much as 50 percent of the weight of the catch from being lost. An effective and not costly method of reducing these losses could provide considerable benefits to the population that depends on traditional fishing for a livelihood. It could at the same time have a beneficial effect on fisheries resources by reducing the size of the catch needed to supply a given amount of fish to the consumer.

c. Post-Harvest Technology

As larger harvests of food grains and other crops become possible, there is a growing need for labor-saving devices that will shell, hull, and grind into flour. Hand-operated machines have long been available, but there is a growing market for devices powered by some other means. Promotion Humaine, the Human Resources Development Department, has embarked on a program that provides motor-driven grain grinders to village groups and trains them in management of the device. The grinders are said to be imported by two of Senegal's larger dealers of agricultural machinery, SISCOMA and MATFORCE. They cost about 500,000 CFA ($2,325). There is heavy demand for use of the grinders. Villagers pay 10 CFA per kilo, which is divided to pay the millers (2 CFA), for gasoline (3 CFA) and amortization (5 CFA). Promotion Humaine officials state that the grinders can be amortized in two years or less.

The ISRA experimental unit at Koumbidia is an example of instances where the introduction of new techniques (in this case a new crop) has led to a perceived need for labor-saving post-harvest technology. One of the more dynamic hamlets of the Koumbidia unit is Keur Lamine. Maize was introduced in 1973, and Keur Lamine is now a heavy producer. Yields average 1.8 tons per hectare and get as high as 4 tons/ha. A shelling machine has therefore been installed to handle the large amounts now harvested.

Such a machine, however powered, can lift one constraint to greater production. Of considerable interest is the question of what use villagers, particularly village women -- who treat the harvested grain crops -- will make of time that is made available to them by the introduction of machines of this kind. One of the more valuable aspects of this project would be the insights it would provide on labor reallocations resulting from the introduction of solar-powered grinders. Highly productive use of time freed from traditional hand grinding would provide an economic justification of the new devices that would be lacking if the time was used only for leisure.

d. Lower Priority Needs

Energy made available at the village level can provide amenities that would serve to make rural life more attractive and perhaps restrain, to some extent, the exodus to towns and cities. While not productive in the same sense as those uses discussed above, these energy applications can provide services that may be highly valued by villagers. Electricity to light individual houses is not something to be envisaged in the foreseeable future, but if electric lighting were available for a couple of hours a night at a community center, this would permit adult literacy and other classes for villagers occupied elsewhere during the day. Kerosene lanterns are now used for such purposes, but the day may not be far distant when solar-produced electricity, used primarily for other tasks in the village, may produce light no more expensive than that from kerosene lanterns.

The use of photovoltaic panels to power television receivers for primary school classrooms is already common in Ivory Coast. Were Senegal to embark on a program of this kind, the modularity of photovoltaic panels would permit educational TV to be combined with other uses in the village.

Rural dispensaries, which are found occasionally in larger, central villages where other forms of infrastructre are present (Méréto in the Terres Neuves zone and Boutou near Tambacounda are examples), could find uses for simple, inexpensive hot water heaters.

A final amenity that could be provided at the village level is the means for readily recharging flashlight and transitor batteries. This use of solar panels has been suggested by the CILSS/Club du Sahel report on energy for development in the Sahel. Flashlights and transitor radios are widely used in rural areas for productive ends as well as leisure. Agricultural extension broadcasts in local languages are known to be one of the most effective ways of getting valuable information on crops to large numbers of farmers. There are also directly productive uses of standard flashlight batteries in such things as an eight-battery cotton insecticide sprayer. ISRA agents state that a set of batteries will be used up in spraying 4.5 hectares. A farmer growing cotton on 1.5 hectares would thus have to change batteries after every third application, of

which there are six to twelve per year. Nine applications a year on 1.5 hectares would require the purchase of 24 batteries, an outlay of as much as $9.60, a not inconsiderable expense for a farmer. Rechargeable batteries could prove worthwhile in such circumstances.

4. Current Renewable Energy Applications in Senegal

Carol Ulinski's Trip Report (1) provides a very useful review of renewable energy efforts underway in Senegal. There is no need to repeat the same information here, except to the extent that the PP team was able to make additions after Ulinski's departure.

One important development was an agreement reached in December between DGRST and the various institutes doing renewable energy research on how responsibilities would be divided among them. The breakdown is as follows.

CERER:*	thermo-dynamics
	solar fish and crop dryers (with help from the Institut de Technologie Alimentaire)
	biomass (with help from ISRA)
	charcoal and fuelwood (possibly with help from the Thiès Polytechnical School)
IUT:	photovoltaics
	windmills (mechanical rather than electrical)
Thiès:	rapid rotation wind generators

Other developments of interest are discussed below.

a. Thermo-dynamic Solar Pumps

The French aid mission readily concedes that the small thermo-dynamic pumps of the SOFRETES variety installed at four village sites are the first and last of their type. Some of the stations will be enlarged to

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*The Institut de Physique Meteorologique (I.P.M.) is in the process of being transformed into the Centre d'Etudes et de Recherches sur les Energies Renouvelables.

pump more water, it having been found that 20 liters per person per day is not sufficient. SOFRETES will also study heat storage and heat losses at the Medina-Dakhar installation; but the general conclusion seems to be that thermo-dynamic solar stations need to be at least 10 kW to be worthwhile.

In addition to the 30 kW station being installed at Bakel under the joint AID-FAC project, two other thermo-dynamic installations will be financed by France. The first, initially planned for Dahra and mentioned in the Fifth Development Plan, is now intended for Bondié Samba, about 40 km north of Kaffrine. The reason Dahra was dropped is that the Senegalese government was expected to contribute a borehole there but never did. The station was originally supposed to have a 10 kW capacity and cost 70 million CFA ($324,000), but SINAES states that plans are being made for a 7 kW station at Bondié Samba. The second new thermo-dynamic installation will be an electrical power plant at Diakhao, 22 km south of Diourbel. The existing diesel station there has been running at a large deficit and has wide fluctuations in demand. The new station will be able to handle a peak load of 23 kW. FAC is providing 40 million CFA ($186,000) for Diakhao, and a substantial French CCCE loan to SENELEC is also involved. The Fifth Plan mentions four other isolated, diesel-powered, deficit-ridden plants that it would like to see replaced by solar installations.

b. Photovoltaic Solar Pumps

As indicated in the Ulinski report, CARITAS Senegal did request funding from the European Development Fund (FED) for 75 percent of the cost of installing 30 Guinard photovoltaic pumps over a three-year period. The FED approved funds for nine, three a year for three years, instead of 30. The project was in fact presented to FED by the Central Agency for Joint Financing Development Programmes, a Roman Catholic bishops' organization in the Netherlands. Since the organization is non-governmental, FED provides funding but has no control over the implementation of the project, which will be in the hands of CARITAS.

By mid-December 1978 CARITAS had identified 13 potential sites for the nine pumps, all of which are grouped in the zone where CARITAS is applying its development efforts, located between M'Bour and Thiadiaye. Two pumps sizes will be used: 1800 W and 2600 W. The former will be installed in the shallower tubewells with a manometric head of 13-20 meters, the latter in tubewells with a head of 20-28 meters. The output expected is 90 to 120 cubic meters per day. This may not satisfy some villages in the zone, which would prefer a motor or electric pump producing up to 300 cubic meters a day, according to CARITAS. To assure that there will be water available at the pump site, even at night or on cloudy days or in case of breakdown, a CARITAS handpump will be installed in a well connected to and filled from the tubewell. (This is based on the forage-puits system that FED is now using elsewhere in Senegal.) CARITAS planned to send its extention agents to the 13 potential sites to discuss the solar pumps with villagers before a definite choice of sites is made.

While the Fifth Plan does mention additional solar pump projects, the PP team found no indication that funding is available. The Terres Neuves resettlement zone is listed for six village pumps producing 30 cubic meters a day, but the director of Terres Neuves did not think that any financing had been found. There is also an item for eight village and pastoral water supply projects, but no sign of a donor. The French aid mission, for its part, has come to the end of a five-year period during which it allotted 300 million CFA ($1.4 million) to thermo-dynamic and wind energy projects. Before embarking on a new set of renewable energy projects, FAC has indicated it intends to analyze the current situation. There appears to be no intention of funding photovoltaic projects in the immediate future. French interest in photovoltaics is not lagging, however. The French Commissariat à l'Energie Solaire (COMES) was one of the organizers of a conference on photovoltaics held in Toulouse in December 1978. Attended by over 130 experts, the conference explored such topical issues as tracking and concentrating the sun's rays on PVC panels, storage of electricity and conversion of direct to alternating current.*

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*Le Monde, 12 December 1978, page one.

A few footnotes on photovoltaics in Senegal may be in order.

1. The photovoltaic pump at the agronomic research center (CNRA) at Bambey does not draw water from a well but rather pumps it from the surface into a 10-meter water tower, whence it is used for drip irrigation. The panels were made by Radio-Technique Compelec, the French subsidiary of Philips. IUT is said to have encountered problems with RTC panels used in its experimental work and to have been obliged to replace them.

2. The M'Babak pump is rated at 1300 W_p. It operates almost ten hours a day, from 8:15/8:30 to 6:00/6:15. Its SOLAREX panels are guaranteed to lose no more than 10 percent of their efficiency after five years.

3. The PP team neither saw nor heard any indication that technical problems had been encountered with the three photovoltaic pumps in Senegal. The one at Toki (900 W_p) had just begun operation; those at M'Babak and CNRA Bambey had been operating since February 1978. The difficulties that seem to have arisen at M'Babak were over the distribution of the water rather than the functioning of the pump. It also appears that neighboring villagers come from as far away as 12 km to seek water at M'Babak, as a result of which 80 cubic meters per day is not sufficient. Visitors to M'Babak from Maison Familiale headquarters in Thiès arrived at 5 p.m. one afternoon to find 200-300 people gathered around the water tanks shortly before the pump would stop for the day.

c. Windmills

Encouraged by successful experimentation with a SAVONIUS-type, vertical axle windmill at Diaglé, SINAES expects to install others in the near future. FAC has provided funds for at least three, to be located at Bidiem Mouride, Keur Bacar (near Tivaouane), and Sao (near Thiès). SINAES hoped to be able to install the latter two in March 1979.

Forty other potential sites which appear to meet SINAES' criteria* had been identified and were inspected by the Water Resources Department

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*The criteria: (a) existence of a well, (b) an adequate supply of non-saline water (5 m^3/hr capacity desired), (c) a village nearby, (d) site not in a depression nor blocked by trees, (e) sufficient wind (see Appendix B.3).

(Hydraulique). Eight of the most attractive were selected for proposals to potential donors. FAC, which has 1978 funding for two more Savonius windmills, may choose one or two of the sites, and AFRICARE may also be interested. The total cost of the windmill, including follow-up technical visits and training of local personnel, is 2,621,000 CFA ($12,200).

Two Aerowatt* generators were scheduled to be installed in the first quarter of 1979. Both are funded by France. At M'Boro, a market gardening training center of Promotion Humaine has been using diesel generators that break down constantly. The 4 kW Aerowatt generator will provide electricity for irrigation, for a cold room to preserve produce and for other uses. FAC has allocated 30 million CFA ($140,000) for the project.

Another Aerowatt is destined for Louli Bentegne, just east of M'Bour in the CARITAS development zone. The electricity produced will be used to power a Guinard pump.

d. UN Experimental Rural Energy Center

This project has received a fair amount of publicity. The original design work for a rural energy center to be established at Ndia Goureye was done by the Brace Research Institute of McGill University. Considerably modified, the project as finally approved by the United Nations in May 1978 will be located instead at Niaga Wolof, 40 km east of Dakar. The total cost was to be $388,000, of which $326,000 would be provided by the UN. The executing agency is the UN Centre of Natural Resources, Energy and Transport.

The objective is to "test the technological viability of the various devices that would be installed to harness the renewable sources of energy at Niaga Wolof and to determine the economic feasibility of production of energy for various end-uses. The socio-economic impact including the social acceptability of the devices, individually and collectively,

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*AEROWATT S.A., 37 rue Chanzy, 75011 - Paris, France.

operating in the environment of the village, would also be determined."

The devices to be tested on a small plot of land next to the village are: (a) A pyrolytic converter to reduce peanut hulls to char, oil and flu-gases. The char would be used for cooking, the oil sold in drums for boiler fuel in Dakar, and the gas used to fire an engine to drive a generator. (b) Dung from 200 head of cattle would be fed into a bio-digester, the resulting methane gas being used to fire a modified conventional internal combustion engine generator of about 14 kW(e) capacity. The electricity would be stored in a battery bank. (c) A solar thermal unit would produce 7.5-10 kW(e) of power. (d) A 2 kW_p photo-voltaic array would be used to pump water from a well into a 15-meter storage tank and also to provide power for the battery bank. (e) A Dunlite 2000 windmill of Australian make mounted on a 10-15 meter tower would generate 8-9 kWh of electricity per day, also to be fed into the battery bank.

Questions about several aspects of this project design might well be raised. The complexity of keeping so many devices operating at once, the matter of how the stored electricity might be used, the sheer amount that is supposed to be produced for a village of 700 people, the questionable efficiency of storing so much of it, the management skills required simply to handle the output and avoid a catastrophic accident; these and other problems come immediately to mind. What is more, the project timetable leaves 10 months to complete installation of the devices, four more to complete construction of the rural energy center, and only three months to conduct tests before a final report must be written. The unrealistic nature of the timetable as well as of the budget, given the capacities of the devices to be installed, makes one think that the whole project will have to be considerably revised. Steps in this direction may well have been taken if, as expected, a CNRET mission visited Senegal after mid-December 1978 to amend the project document.

References:

[1] Ulinski, Carol A. "Trip Report: Senegal Renewable Energy Project," submitted to AFR/DR/SDP November 30, 1978.

APPENDIX B

TECHNICAL ANALYSIS

1. Photovoltaic Water Pump

At the present time, the cost of photovoltaic energy conversion is too high for all but a few special applications. Among these are satellite power supplies and power for remote communications and signaling equipment. However, the price is dropping rapidly due primarily to large research, development and demonstration programs funded by the U.S. Department of Energy (DOE). The DOE cost-reduction program proceeds along four major routes. The first is known as "market pull." Substantial purchases of solar cells by DOE are supposed to pull the price down through economies of scale and introduction of less costly production techniques. Large purchases for installation in the Sahel would obviously contribute to "market pull."

The second route is strong R & D support for lower cost production of single crystal silicon and improved fabrication techniques for single-crystal silicon solar cells (the standard solar cell). Edge-defined crystal growth, ion implantation and laser annealing are some aspects of this program.

R & D support for new single-crystal systems is a third route. The fourth route is development of thin-film solar cells such as amorphous silicon or cadmium sulphide-cuprous sulphide films. Because of the small amount of material used, elimination of the need for large single crystals and the possibility for use of low cost production techniques such as reactive sputtering, it is hoped to reduce solar cell costs to $0.30 (in 1975 dollars) per peak watt in the 1990s. The price goals of DOE are shown in Figure B-1. The costs are given in dollars per peak watt, as a function of time. A solar panel which produced one watt of power when illuminated with 1000 W/m^2 at 28°C is rated at $1W_p$. Normal noontime illumination in Dakar is usually closer to 800 $watts/m^2$ so that the actual peak performance will be about 80% of the manufacturer's rated performance. Included in Figure B-1 are points showing actual sales of solar panels. It can be seen that the price has been falling as projected.

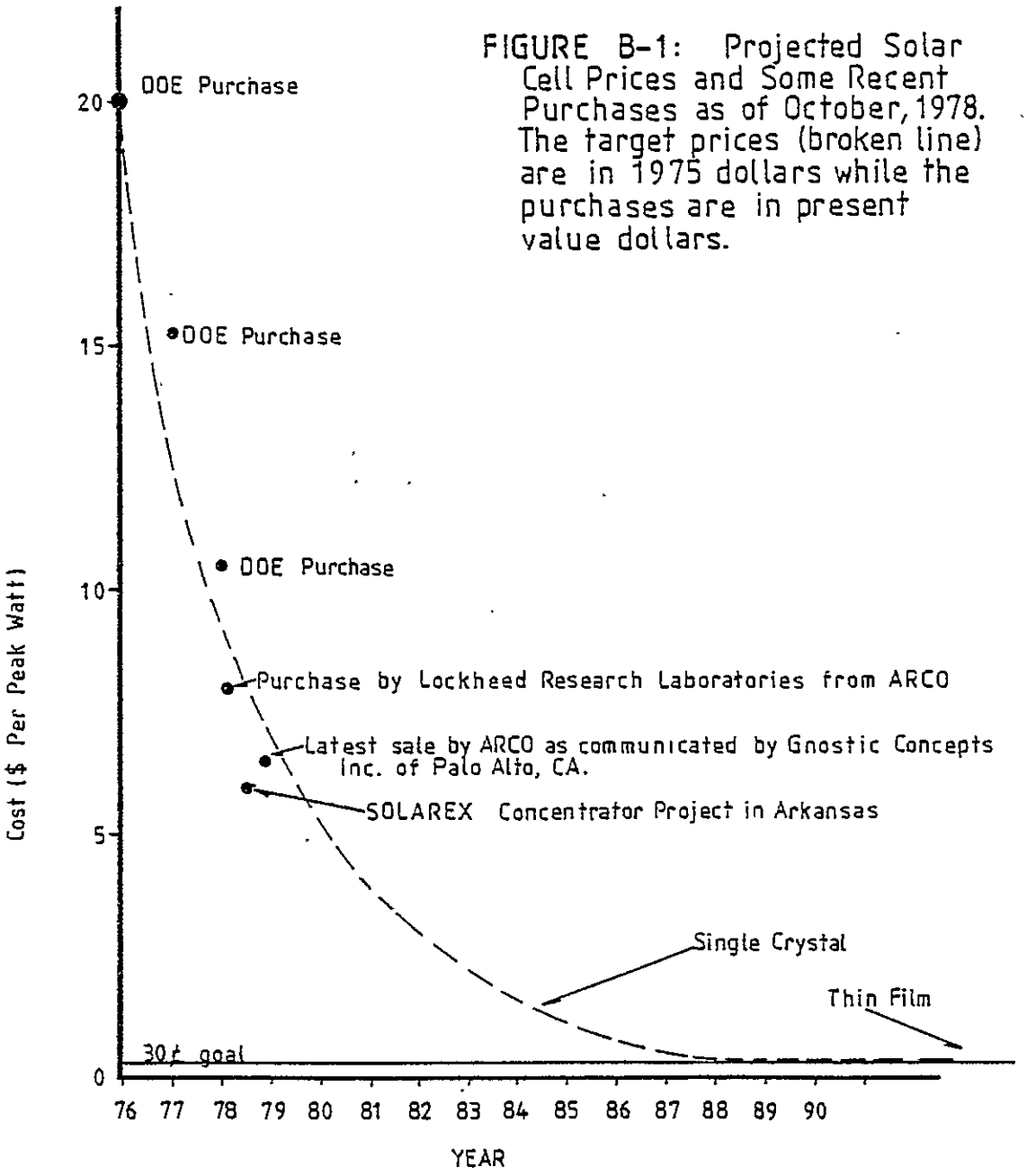

FIGURE B-1: Projected Solar Cell Prices and Some Recent Purchases as of October, 1978. The target prices (broken line) are in 1975 dollars while the purchases are in present value dollars.

The total cost of, for example, a photovoltaic water pump is still prohibitively high. A 900 W_p (rated) unit has been installed in West Africa for about $54,000.* The cost of the solar panels at the factory was about $14,000. The difference -- $40,000 -- represented the cost of middlemen, shipping, mounting, travel and expenses for experts, pump, storage tank, fencing, and controls. This was an early installation (1977); the price of later ones in Senegal and Mali was lower.

It can be seen that reduction of the price of solar cells is probable, though we must await developments in manufacturing, and reduction of the peripheral costs is possible. These latter costs are the largest part and we can do something about them. The costs of experts can eventually be reduced to zero. Fencing, buildings and reservoirs can be constructed in traditional and inexpensive ways. In many cases, no buildings or reservoirs are needed. The middleman markups can be eliminated.** The photovoltaic pump installations planned for this program should benefit from reductions in all these areas.

We will consider pumping of irrigation water from the Gambia River at Bantantinti, Senegal, using a 2 kW_p photovoltaic pump. The price of such a pump is given by Solar Power Corporation, Woburn, Mass. as $29,000 plus $3,000 for transportation.*** It is assumed that taxes and duties ($10,000) will be waived. During the month of April, this system can pump about 90 m^3 per day from the river, which is 15 meters below the irrigated field. Depending on the crop, this is enough to irrigate up to two hectares. The solar panels will be mounted up on the bank. Power lines will lead down to the pump which will be on a floating platform. No reservoir is needed since (a) insolation is nearly uninterrupted during the dry season, (b) it is not necessary to irrigate every day, and (c) the solar pump will be a base-line pump (running every day) with nearby diesel pumps supplying peak demand.

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*The pump at Koni, Mali, installed July 1977.

**See the discussion on page I-2 of the Project Paper Appendices of the Mali Renewable Energy Project Paper, USAID, June 1978.

***Information from Jean-Louis Geneste, Market Development Manager for Solar Power Corporation in Africa, Dakar.

The installation will be the responsibility of SINAES with assistance from villagers and advice from the manufacturer's local representative. The enclosure for the solar panels and controls will be constructed locally of local materials. The total cost will be:

	First Installation	Second Installation
Pump, regulator, solar panels and accessories	$29,000	$29,000
Shipping to Dakar	3,000	3,000
SINAES installation costs (engineering, site preparation, shipment to site, local labor, installation, testing, training of villagers, contingency)	10,000	6,000
	$42,000	$38,000

Maintenance and procurement of performance data will be done by local people. There will be no full time operator. SINAES personnel in Dakar and the manufacturer will verify performance and make major repairs if necessary.

2. Photovoltaic Village Power Supply (Centrale Photovoltaique Villageoise)

In section 1, we showed how the price of photovoltaic systems can be expected to diminish to a reasonable level. This is a necessary first step in making them cost-effective. Capital-intensive systems such as these must be used continuously since capital costs must be paid whether or not the systems are being used. These two ideas generate the concept of a general purpose photovoltaic power supply with uses varied enough to make it likely that it will be used a large part of the time.

Such systems have been designed and are being installed by the NASA Lewis Research Laboratory. One is a photovoltaic system for the Papago Indian village of Schuchuli, New Mexico, which provides water pumping, lighting and domestic services (1). It is a 3.5 kW_p system funded by DOE.

Another is for the village of Tangaye in Upper Volta (2). The 1.8 kW_p system funded by USAID supplies power for water pumping and grain grinding. A larger system has been designed and installed by Lincoln Laboratory and the University of Nebraska at Mead, Nebraska. It is a 25 kW irrigation and grain drying system (3). We suggest similar systems for Senegal under this program.

A planned system is shown in Figure B-2. It is a 2 kW_p system providing water pumping, grain grinding, battery charging (flashlights, radios, etc.), lighting, communications and refrigeration. Of course, these functions could be changed to suit particular conditions. A building, as shown in Figure B-3, would house the batteries, control, grinder and perhaps other user functions. The characteristics of this system are:

Energy per day: about 10 kWh in April in Tambacounda*

Peak power: 2 kW at an insolation of 800 W/m^2

Voltage: 120 VDC

Photovoltaic panels: 120 ARCO ASI 16-1200 panels rated at 20 W_p at an insolation of 1000 W/m^2.

Electrical storage: Batteries with 60 kWh capacity

Energy partitioning during dry season: Pumping water from a 20 m deep well to supply
- 250 cattle at 40 l/head day
- 125 sheep at 4 l/head day
- 750 people at 30 l/person day
- 1/4 hectare garden at 17,500 l/day

requires 50,000 l/day. This can be done with 7.5 kWh per day using a motorpump set whose efficiency is 40%. The remaining 2.5 kWh per day will be used for loads other than water pumping. (This partitioning will change to about a 50-50 split between water pumping and other purposes during the rainy season).

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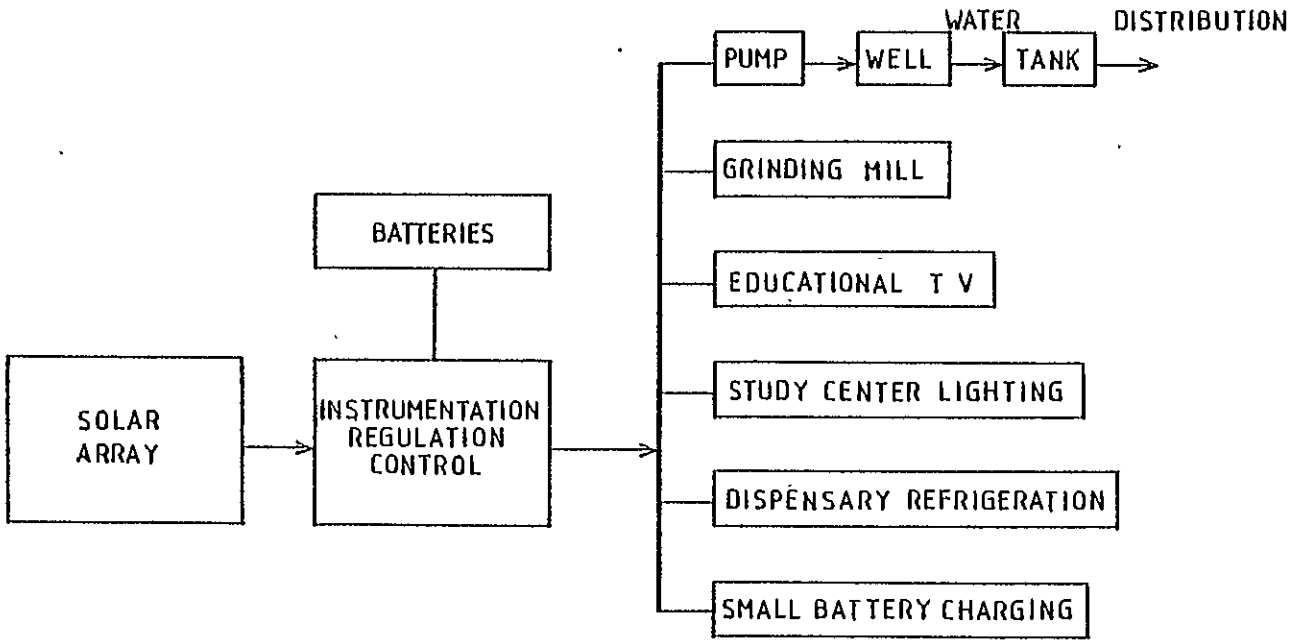
*Since pyranometer in Tambacounda is said to be improperly calibrated (M. N'Diaye, Meteorological Service, Dakar, Yoff) one can give only approximate values.

FIGURE B-2 PHOTO VOLTAIC VILLAGE ELECTRIC POWER SUPPLY



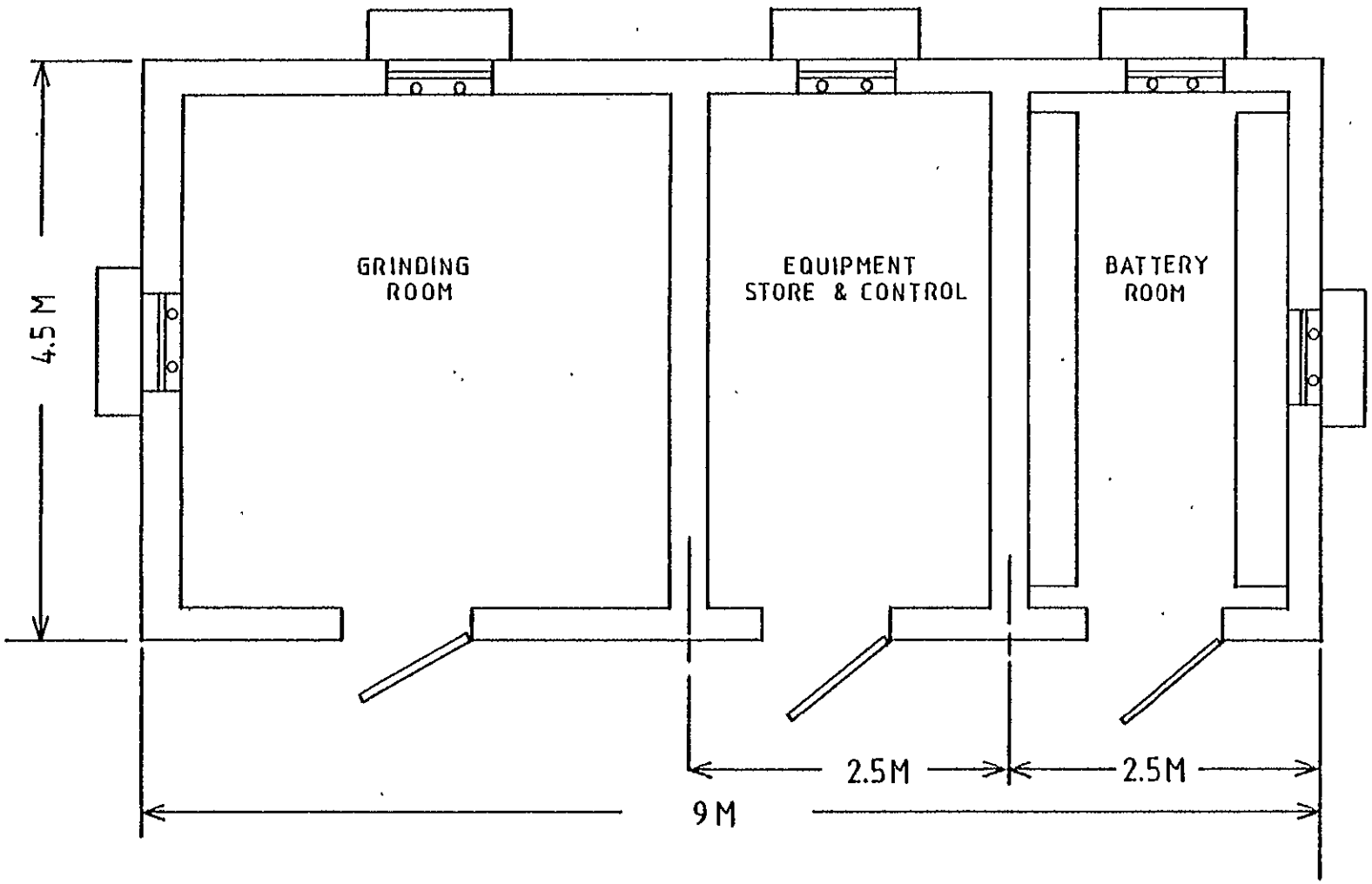

GRINDING
ROOM
EQUIPMENT
STORE & CONTROL
BATTERY
ROOM
4.5 M
2.5M
2.5M
9 M

FIGURE B-3

The costs of this system are:

	First Installation	Second Installation
Solar Panels (120 at $255 each)*	$ 27,000	$ 27,000
Structure, materials, wiring, assembly	5,000	5,000
Batteries	2,500	2,500
Controls, instruments, assembly	8,000	7,000
Water pump, motor, plumbing	1,500	1,500
Grain grinder and spares	2,500	2,500
Other loads (refrigerator, TV, corn shellers)	3,000	3,000
Water tank and distribution system (25,000 l)	8,000	8,000
Design, Engineering and Start-up		
SINAES and subcontractors	25,000	8,000
U.S. Technical assistance	25,000	3,000
Building to house controls, batteries, office and loads	14,000	14,000
Shipping	10,000	10,000
Contingency	15,000	10,000
	$136,500	$101,500

A large part of the design and engineering has already been done by the NASA Lewis Laboratory so that the "Design" item may be somewhat smaller than the amount indicated.

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*According to the sales literature, the ARCO ASI 16-1200 panels, rated at 20 W_p, are $255 each. This system will produce about 2 kWh at a location such as Bantantinti where we assume the peak insolation to be about 800 W/m^2. However, it is rated as a 2.4 kW_p system since an insolation of 1000 W/m^2 is used for rating panels.

The operating costs will be (per year):

	First Installation	Second Installation
Operator (village person to be compensated by villagers)	-	-
Periodic Visits by Engineer (SINAES)	4,600	4,600
Contingency for repair & maintenance	1,000	1,000
	$5,600	$5,600

In contrast to the photovoltaic water pump, which is simple enough not to require an operator, this system will require an operator who will regulate use, keep records of operation, perform routine maintenance, check for malfunctions and interact with the users. Because of its novelty and relative complexity it will also require periodic visits by an engineer who will collect operating records and make sure the equipment is operating properly. He will regularly instruct the operator concerning the principles of operation, operating methods, and maintenance. He will correct equipment malfunctions and operating inadequacies in cooperation with the operator. It is expected that the actions of the visiting engineer in his role of technical information gatherer, corrector, and instructor will enable the local operator to progressively acquire a larger role for himself and the village, resulting finally in nearly complete local competence and nearly complete local operation of the installation. The operating costs, however, will be expected to remain nearly constant since the decreasing cost of visits by the engineer is expected to be compensated by increasing costs of maintenance as the equipment ages.

This system could be installed in villages such as Keur Lamine, Botou or Koussanar in Senegal Oriental. The partitioning of water among cattle, people and irrigation can, of course, be adjusted to suit the particular situation. Alternatively, more energy could be used for things other than water pumping or the size of the installation could be changed. From pres-

ent experience (Nabasso, Mali, or Medina Dakhar, Senegal) it is known that cattle and/or people will move in to quickly absorb and exceed the system capacity. The sizing of the system must be done with this mobility phenomenon in mind.

References:

[1]Bifano, W.J., et al., "Design and Fabrication of a Photovoltaic Power System for the Papago Indian Village of Schuchuli (Gunsight), Arizona," Report DOE/NASA/1022-78/39. Paper presented at the 13th Photovoltaic Specialists Conference, June 5-8, 1978.

[2]Report of Design Review Meeting, "Solar Cell Power System Demonstration for Upper Volta Project" USAID, Washington, D.C., June 29, 1978.

[3]Matlin, R.W., et al., "The 25-kilowatt Photovoltaic-Powered Agricultural Experiment at Mead, Nebraska," Report COO/4094-4, MIT Lincoln Laboratory, Lexington, Mass., 02173, 21 April 1978.

3. Windmills for Pumping Water

A windmill needed for rural use in Senegal (and Sahelian countries in general) must have some properties that are not needed in many other countries. Because wind speeds are low, it must have a low cut-in speed (vitesse de démarrage) and the power versus wind speed curve must rise rapidly immediately after the cut-in speed. The windmill must be very rugged, it must require very little maintenance, the maintenance should be simple, and repair should be simple. Parts should be available. The machine should be self-protecting in high winds. It should be resistant to sand and dust. Preferably, it should be capable of being manufactured in Senegal. It should be well proven in actual service. Its cost should be low.

We consider three types. The American multiblade type and the sail type (Greece or Holland) have been well proven in service but, except for a promising beginning in Ethiopia (1), not in the Sahel. Tewari claims that the sail windmill is economically competitive in India (2). Development of a Savonius vertical axis machine has begun in Senegal, and the first field installation was made at Diaglé in January 1978. SINAES, which put in the Diaglé windmill, believes that several of the weak

points demonstrated in previous windmill attempts in Africa have been eliminated in the Savonius design, though more work needs to be done to make the machine completely reliable. SINAES plans to work with Ets. Mengin in France and with I.U.T. in Dakar on further improvements. The ameliorations already incorporated include: (a) a hydraulic transmission replacing the mechanical one which so often warps and breaks; (b) a light (10 kg.) Vergnet pump which can easily be pulled and repaired by villagers; and (c) elimination of the need to shut down the windmill in a high wind.

The relevant properties of the three types (Savonius, American multiblade and sail) are shown in Table B-1. The number given in the last column is the maximum fraction of the power density of the wind stream that the windmill can extract. It is taken from Wilson, et al.(3).

It would be useful to calculate and compare the energy output of these three types at Louga, which is at the margin of the high wind area (see Appendix A) and for which there is some wind distribution data. Unfortunately the performance curves of these three windmills were not available to the PP team in Dakar. Furthermore, the wind velocity distributions for Louga in 1963 are higher than the average for other years (4). Thus, at this time, we do not have the input data needed to make reliable calculations of windmill performance at Louga. We can make some guesses. From Figure B-4, we see than the Aerowatt machine, for which we do have a performance curve, operates at full power only 80 hours in May and 35 hours in January or July. When one considers that 1963 is reported to have been windier than usual and that the French Aerowatt generator performs with higher efficiency than those considered here (maximum efficiency of the 2- or 3-blade high-speed Aerowatt should be around 0.45), one is left with some doubt as to whether Louga is not too far inland to have enough wind to make windmills cost-effective.

Some data on quantity of water pumped by Louga windmills are given by Bremond (4). For example, during May 1963, three windmills performed as shown in Table B-2.

TABLE B-1. RELEVANT PROPERTIES OF THREE TYPES OF WINDMILLS

Type of Windmill	Low Wind Speed Performance	Maintenance Repair Parts	Operator Attention	Protection From High Winds	Proven in Service	Local Manufacture	Cost	Lifetime	Maximum Efficiency
American multi-blade	Starts at about 4m/s	Medium	Shut off in high wind & when no water is needed	Needs Operator	Extensive but not in Sahel	Import gear box & bearings	Moderate	Long	0.3
Sail Type	Probably better	High but more can be done locally	Remove sails in high wind & when no water is needed	Needs Operator	Extensive but very little in Sahel	Yes	Lower	Short	0.15
Savonius Vertical Axis	Claimed to be Better	Potentially Low	Shut off when no water is needed	Self Protecting	Not extensively proven	Yes Import bearings	Moderate when in production	Long	0.12

FIGURE B-4 Time distribution of wind speeds at Louga in 1963 at a height of 15 meters. The power output of an electric power generating wind machine as a function of wind velocity is also shown.

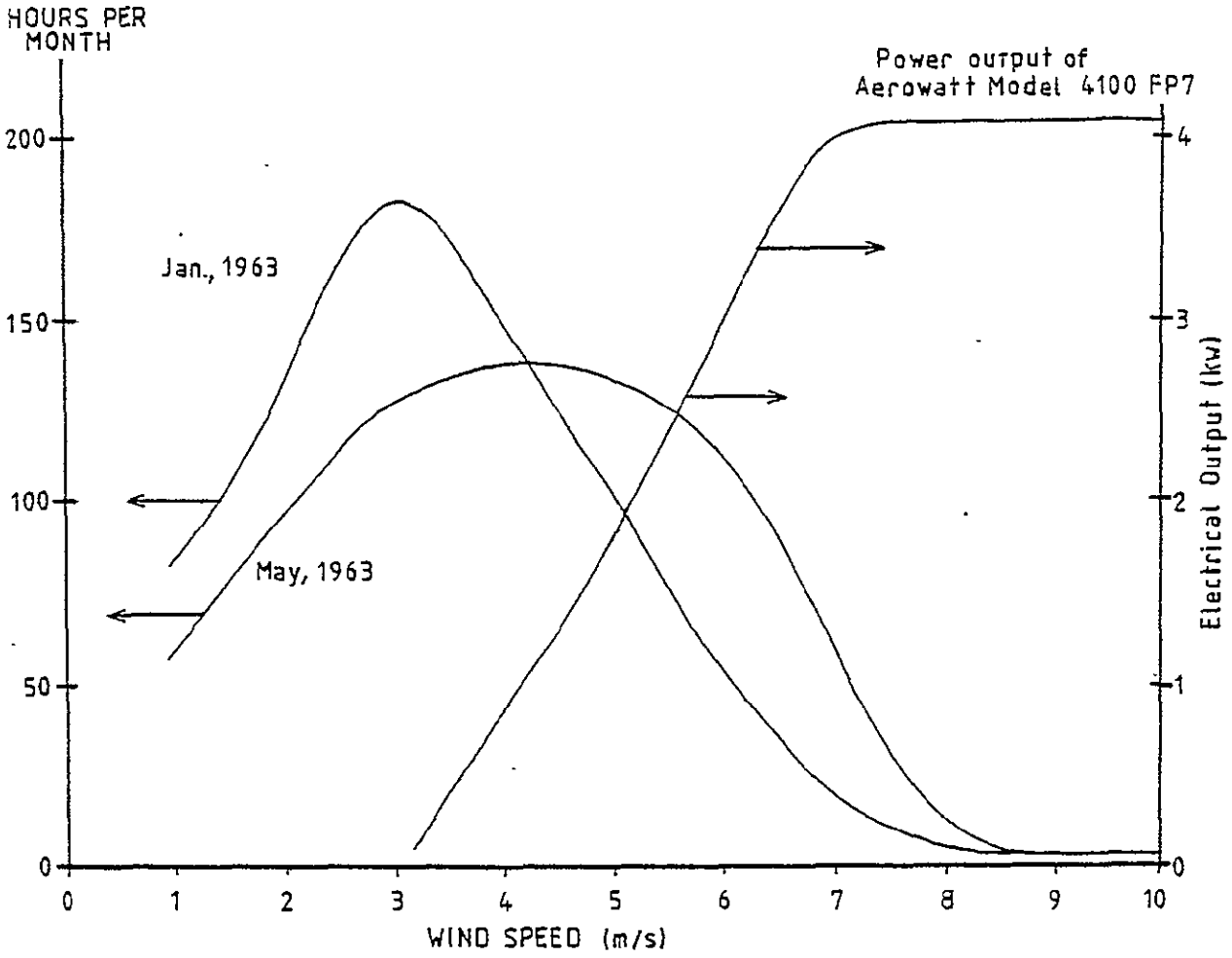

TABLE B-2. COMPARISON OF WINDMILL PERFORMANCE

Type	Diameter (m)	Water Pumped (m^3)	Height (m)
Aeromotor 3 1/4" x 68	6.1	1103	18
Hercules FL 5 3/4"	4.27	204	15
CAME H.R.	6.0	44	15

These were all multiblade "American" type windmills pumping from a 21-meter depth. The low output of the CAME was explained by a poor pump. The low output of the Hercules is partly due to its size (area of wheel is 1/2 of that of the Aeromotor). The only good performer was the Aeromotor, which averaged 36 m^3 per day. This is 60 kwh of useful energy, and it would replace about 120 kwh of other energy assuming a motor-pump efficiency of 50%.

A striking feature of this set of tests was the number of breakdowns that occurred. The Hercules operated 10 months before breakdown, the CAME for four months and the Aeromotor broke down three times in six months. It was always the pump that broke. A similar rash of breakdowns occurred with a group of six windmills which the Ecole Polytechnique of Thiès put into operation (5). A wide variety of breakdowns was reported and only two of the six were operating at the time of the report, 20 March 1978.

The foregoing discussion illustrates two major problems -- low wind velocity and breakdowns. These problems need to be taken seriously into account. Wind velocities would be measured at the exact locations proposed for windmill installation, all of which would be in the coastal belt between Dakar and St. Louis. Spare parts supplies will be assured for the life of the program, and strong attempts would be made to involve the village people in the program in such a way that the maintenance and care of the windmill be assured.

Two windmills would eventually be installed. They would be chosen from the three types listed in Table B-1 or from similar ones. Initial development work on the sail type will be necessary. This will be done at the Hydraulic Laboratory of the Faculté des Sciences of the University of Dakar under the direction of Professor Le Gorières. In fact, this model need not necessarily be a sail type. Any locally constructable and maintainable windmill that operates well at lower wind velocities would be appropriate.

A choice among the windmills would be made about 15 months after the beginning of the project since a full 12 months of wind data from the potential windmill sites is required. The cost of installing windmills at remote locations (tubewell not included) is:

Savonius type*

Cost at factory	$ 8,500
Transport, installation, training of local personnel & one year of maintenance	3,800
10% Contingency	1,200
	$13,500

American Aeromotor**

(6.1 m diam., 16.2 m tower) with watering trough and 40 m^3 reservoir

Foreign exchange costs	$15,000
Local Costs	7,000
	$22,000

Locally made sail type, 4 m diameter***

Cost of building prototype on site including test and startup	$10,000
20 m^3 reservoir	5,000
	$15,000

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*1977-1978 cost of model as stated by SINAES.

**Reference 4, p. 39.

***Must have a tower at least 15 m high. Note that there would be about $25,000 in R & D costs at the Faculty of Sciences, including staff salaries and the cost of materials for the development and testing of a prototype.

These costs seem high but appear to be well verified. In two cases, they are actual costs. The cost of the Aeromotor is an actual cost for an installation in Gao, Mali in about 1960 (6) (one of the Gao windmills mentioned in the Mali Renewable Energy Project Paper, June 1978.) The cost of the sail machine as stated here is probably low since it must have at least a 15-meter tower. The wind energy available is a very rapidly increasing function of height as pointed out by Bremond (4). The tower is a major cost component for a windmill.

References:

[1]Fraenkel, P., "Food from Windmills," Intermediate Technology Development Group Ltd., London, (1975).

[2]Tewari, S.K., "Economics of Wind Energy Use for Irrigation in India," Science, Vol. 202, 481 (3 Nov. 1978).

[3]Wilson, R.E., et al., "Applied Aerodynamics of Wind Power Machines," Report from Oregon State University, Corvallis, Oregon 97331 (1974).

[4]Bremond, R., "Rapport d'Interpretation des Resultats obtenus au Centre Expérimental des Eoliennes de Louga (Senegal)," Diffusé par le "Comité Inter-Africain d'Etudes Hydrauliques" Immeuble Maine-Montparnasse, 15, square Max-Hymans, Paris 15ème.

[5]Houmaire, F., "Les Eoliennes à l'Ecole Polytechnique de Thiès," Presentation au Colloque du 20 Mars 1978 sur les Différentes Sources d'Energie au Sénégal. Report available from Ecole Polytechnique de Thiès, Senegal.

[6]Cheret, I. (editor), "Etude du Régime des Vents en Afrique Occidentale," Report of the work at Louga, Senegal and Gao, Mali. Service de l'Hydraulique de l'A.O.F. (1962).

4. Fish Drying

Almost all food drying is done by direct solar drying. Fruits, vegetables, cereals, fish and even meat are dried simply by placing the produce where air can circulate around it and sunlight can fall on it. Solar drying by use of special equipment is possible in a highly mechanized agricultural system, as in the United States, where grains, hay, etc., may be harvested with a moisture content somewhat higher than is acceptable yet cannot easily be spread out to dry in the sun. In a less mechanized agricultural system this situation does not exist. There are nonetheless a

few special situations where the use of solar drying equipment may be advantageous. In Senegal one such situation is fish drying.

Fish are traditionally dired on racks raised above the ground for good air circulation and exposure to sunlight. However, insects grow in the fish during the drying process and consume as much as 50 percent of the weight of the fish. This loss can be avoided by drying the fish at a higher temperature (50°C to 60°C) in a specially constructed solar fish dryer. The higher temperature kills the insects.

Such a dryer consists of a flat plate solar heat collector which heats air. The hot air flows by the thermal syphon effect into an insulated compartment in which the fish is placed on racks. Complete drying can be accomplished in 2 to 3 days without loss. Research on such dryers has been underway in Dakar for almost ten years but lack of funds and of interest have precluded introducing this technique into the fishing villages of Senegal. The need remains, however, and because some new ideas have appeared, it seems worthwhile at this time to make a serious effort to test solar fish dryers in the field.

Attention must be paid to the cost of the apparatus. The cost must be kept down without sacrificing durability and proper functioning. Work needs to be done on the techniques involved in the drying process. It is now thought that turnover time can be reduced significantly. The process may start with drying on traditional racks, followed by one day only in the dryer to kill the insects and finally completed by a period on the traditional racks. Attention must be paid to product quality and consumer acceptance. The nutritional value may be changed as a result of higher temperatures, and taste and appearance will be different. The Institut de Technologie Alimentaire (ITA) will study these effects closely. Participation on the part of villagers and marketing of the product are important considerations also. The strongest incentive to acceptance and participation may be the potential for nearly doubling output.

The program will build upon the results obtained from a 20 m^2 prototype dryer soon to be set up at CERER. For the first time expanded concrete will be used as a structural and insulation material. Glass of 3 mm thickness will be used as the collector cover. Operational performance

would be optimized. Temperatures, air flow rates, drying procedures, and yield would be determined. Then a 100 m^2 dryer would be constructed and put into operation in a village such as Kayar, M'Bour or Joal. The village should be within easy reach of Dakar.

CERER will cooperate with the village, intensively at first as procedures are worked out and instruction is given. ITA will cooperate in the development of the drying process and in the analysis of the product.

The cost will be:

Construction of 20 m^2 unit at CERER	$ -*
Development and testing of the 20 m^2 unit (instruments, salaries of CERER staff, other costs)	8,000
Construction of 100 m^2 unit	22,000
Tests, monitoring, instruction by CERER, ITA	25,000
	$54,000

The 20 m^2 unit should be completed before the end of 1979. The construction of the 100 m^2 unit in the village is scheduled to begin in November 1979, if funds become available. It will take about six months to complete.

5. Biogas Production from Cattle Manure

Recent work by the Cornell (1) and Wisconsin (2) biogas generation groups indicates that biogas generation from cattle manure is economically viable in the United States. Direct translation of their conclusion to the Senegalese situation cannot be made. The costs of construction, operation, and maintenance are different. The value of the energy produced is different. When one considers that electrical energy in a remote area of

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*The funds for construction of this item ($7,000) have already been furnished by GOS.

Senegal costs an estimated $1 per kWh compared to $0.05 per kWh cost in the U.S., it appears that a biogas generator in such a remote area would be more cost-effective than it would be in the U.S. The Cornell and Wisconsin work indicates, in addition, that installations smaller than a 125 cow-unit (utilizing 100% of the manure) are not cost-effective. These ideas are used as a guideline in the following estimations.

Prospective locations for a biogas generator are M'Bar Toubab (Bourdé Doudal) in the Ferlo Valley, Bantantinti on the Upper Gambia river and a village or group of villages in the Terres Neuves in Senegal Oriental. The design and cost estimation will be done for M'Bar Toubab since more specific information is available for it than for the other sites.

The M'Bar Toubab biogas generator will utilize the collectable fraction of the manure form 5000 cattle, a day's watering load, to generate biogas to run the water pumping engine. Additional electrical energy may be available for other uses such as a refrigeration, lights or communications equipment. Part of the water can also be used to irrigate a vegetable garden of about 1 hectare. The sludge from the digester will be used to fertilize the garden and perhaps unirrigated fields. A sketch of the installation is shown in Figure B-5.

The biodigester consists of a mixing feed chamber, a digester compartment, a gas storage compartment (which may be the upper part of the digester compartment as in the Gobar digester) and a sludge storage pit. A motor-generator set and suitable controls use the gas directly to produce electric power. This will all be housed in an enclosure near the well.

The numerical data are taken to be:*

- 5000 cattle produce 10 kg. of wet dung per day per cow; 10% of this is assumed to be economically collectable so that 5000 kg. of wet dung or about 1000 kg. of dry solids per day are available for the digester feedstock.
- The energy output will be about 300 m^3 of gas per day. This has a heat content of 1300 kWh. (In this calculation

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*Data from references (1-4) and estimations regarding differences between the different countries (U.S., India, Senegal) were used in arriving at these estimations.

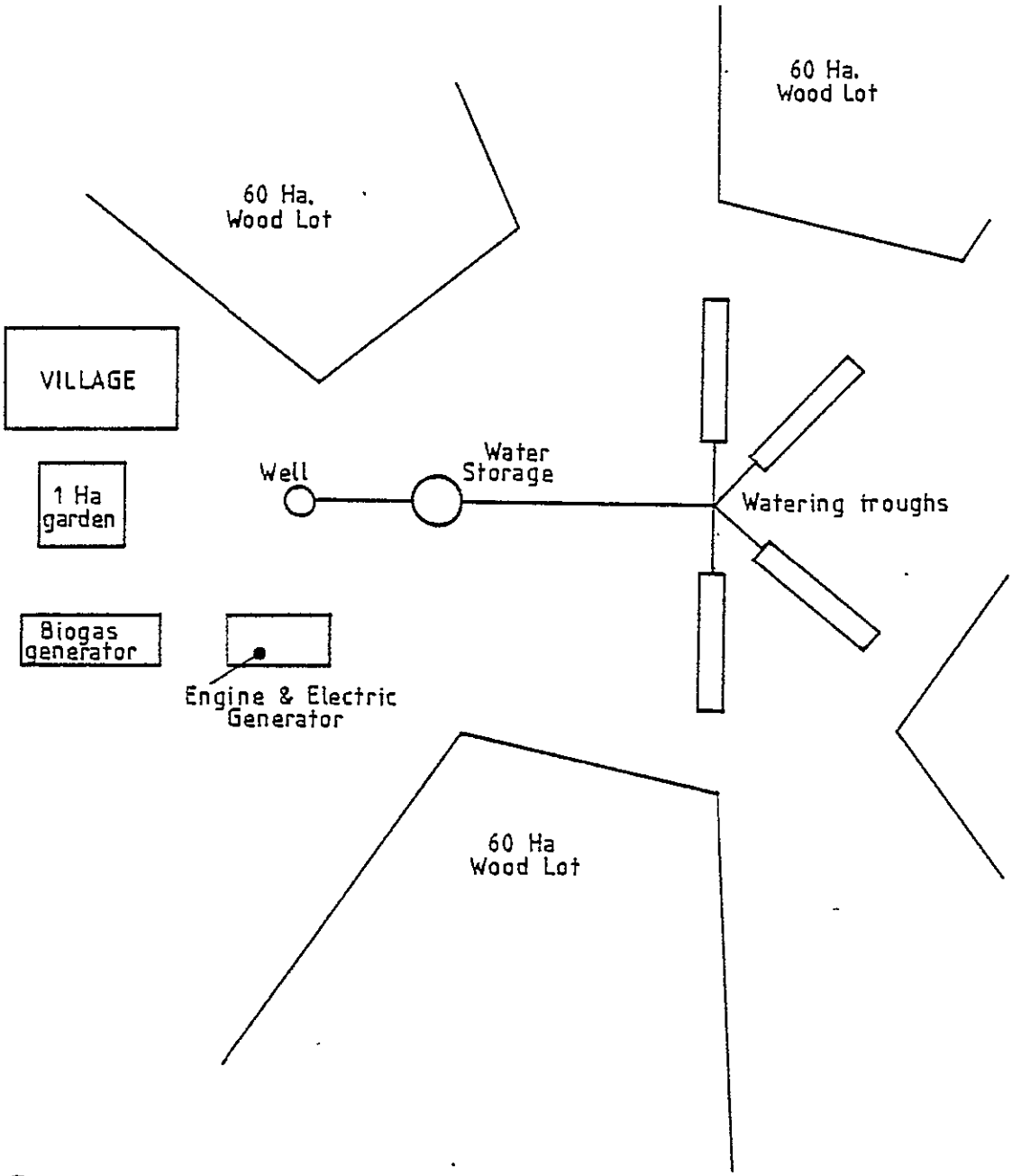


FIGURE B-5 Example of Layout of the Biogas generator at the M'Bar Toubab Watering Point

we have assumed 0.5 m^3 of gas per kg. of dry solids and 15,000 kJ of energy per m^3 of gas.)

- The motor, generator set will have an efficiency of 20% so that 260 kWh of electrical energy will be produced each day. This is enough to run a 25 kW pump for 10 hours a day. It is enough to pump water from the (80 m deep) well for 10,000 cattle per day and to irrigate one hectare.* The waste heat from the motor will be used to heat the digester.
- The digester tank must have a volume of 350 m^3 for an average 50 day retention time.

The construction and installation costs are:**

Digester construction, installation and startup:	
a. Foreign exchange costs: $30,000	$120,000
gas collection pump, fuel injection system for diesel motors compressor controls (valving & electrical) pressure bottles and filling system shipping	
b. Local procurement, construction, installation and startup: $90,000 (SINAES)	
U.S. technical assistance	21,500
Engine modification	1,000
a. Foreign exchange costs (parts): $500	
b. SINAES: $500	
	$142,500

*Ten thousand cattle are watered, 5000 each day, so that there are 5000 cattle (average) in the area of the well at any time. It is assumed that they consume 30 l/day cow and that the garden requires 70,000 l/day making a grand total of 370,000 l/day.

**Data from references (1-4) and estimations regarding cost differences between the different countries (U.S., India, Senegal) were used in arriving at these cost estimations.

The operation and maintenance costs per year would be:

Operator (to be compensated by local arrangement)	-
Dung collection cost	2,400
Maintenance (parts)	2,000
Periodic visits by SINAES engineer	4,600

All other parts of the facility such as the motor-generator set, water storage and distribution, pump maintenance shop, etc. will be funded by SODESP (USAID Project 685-0224).

The collection of manure and the distribution of sludge will be done by donkey cart. Distribution will be a contribution by the villagers. If this cannot be arranged additional annual charges for labor must be added.

The same type of unit of approximately the same size could be installed at Bantantinti. The herd of 1000 cattle, more closely confined than at M'Bar Toubab so that the collection efficiency can be 50%, will supply the needed feedstock. The biogas would supply a single 37.5 hp motor-pump set for pumping irrigation water out of the Gambia River. The sludge would all be used in the irrigated fields as fertilizer.

There will be a need for a cold room for storage of fresh produce at Bantantinti. If this is a room of dimensions 5 m x 4 m x 3 m insulated with 10 cm of polyfoam, one could cool it to 4°C with a cooler consuming about 25 kWh per day. This would consume about 10% of the output of the biogas generator. For convenience, a gas fired absorption cooling unit will be used.

The additional cost would be:

3 ton absorption cooling unit	$ 3,500
Procurement & delivery	2,500
Building and insulated room	12,000
Contingency	3,000
	$21,000

References:

[1]Jewell, W.J., et al., "Bioconversion of Agricultural Wastes for Pollution and Energy Conversion," Final Report, NSF-RANN and AERT 741222 A01. NTIS N° TID-27164, (1976).

[2]Abeles, T.P., et al., "Energy and Economic Assessment of Anaerobic Digesters and Biofuels for Rural Waste Management," OASIS 2000, University of Wisconsin Center - Barron County, Rice Lake, Wisconsin 54868, EPA Contract N° R-804-457-010 (1978).

[3]National Academy of Sciences Ad Hoc Panel, "Methane Generation from Human, Animal and Agricultural Wastes," NAS, Washington, D.C. (1977).

[4]Meynell, Peter-John, "Methane: Planning a Digester," Prism Press, Dorchester, Dorset, (1976).

6. Improved Charcoal Making

The CILSS report has convincingly argued that cooking with wood rather than charcoal would reduce the weight of forest wood that need be cut (1). This is primarily a result of the low wood-to-charcoal conversion efficiency which is obtained from traditional production methods. It is variously estimated at 10 to 22% (charcoal weight/dry wood weight) (1,2). Even when relative cooking efficiencies and transport costs are taken into account, the economic advantage still lies with wood.

From reference (1) the weight of forest wood that must be cut in order to boil 1,000 liters of water is 330 kg. for wood burning and 830 kg. for charcoal burning. With improved stoves it was estimated to be 65 kg. for wood burning and 160 kg. for charcoal burning. This illustrates that it is considerably less wasteful of forest resources to burn wood and use improved stoves.

Nonetheless, it is expected that charcoal will continue to be used extensively in Senegal, particularly in Dakar and Thiès (3). Relatively smokeless fires and a clear preference for charcoal are impulses for the high level of consumption. It would therefore be wise to develop more efficient methods for making charcoal. Development of more efficient cooking stoves will be discussed in section 7.

Traditional charcoal production in Senegal is described briefly by Greathouse and Hradsky (2). The wood is stacked in a large mound around

a central vertical post. It is covered with straw and then with dirt to prevent air from entering. The post is withdrawn and a fire is started in the center hole. When it is burning well the center hole is sealed and air holes are opened in the sides at the proper times. When the smoke stops, after 10-14 days, the holes are sealed and the pile is allowed to cool. The yield may be 20%.

A FAO-UNDP-sponsored forestry project in Ziguinchor (4) has experimented with numerous charcoal making methods. One has been found which yields 30%. It is a modification of the traditional process. Instead of building the stack directly on the ground, an air space is built underneath by means of a network of logs (see Figure B-6). A steel air conduit leads from this air space to a chimney placed beside the stack. This air space and chimney replace the traditional openings in the side. Apparently, this method of air handling during the burning phase results in better combustion of the volatile gases and/or less heat loss from the stack.

Other methods such as the Uganda Mark V kiln and the "Petit-Four" both using steel containers, have been investigated by the project. The steel containers cost about $1000 and must be transported to the charcoal-making site -- both disadvantages.

Creosote and other liquids and gases are lost during the charcoal-making process. The forestry project has begun attempts to collect some of these by using a condenser. Progress in this direction could, of course, result in the development of a complete pyrolysis plant in which solids (char or charcoal), liquids, and gases are all collected as efficiently as possible. The project's apparent aim, however, is to discover a rustic, locally constructable and operable device of the "Jamaica Retort" type -- a VITA design.

An increase in charcoal yield from 20% to 30% will produce dramatic results since it is the major fuel of the Dakar-Thiès resident. At a constant charcoal consumption rate, forest cutting could be reduced by almost 50%. The proposed USAID fuelwood production project in the Bandia Forest near Dakar-Thiès would produce 50% more fuel. Therefore, a major emphasis of this Project will be a program for developing and spreading improved charcoal making methods.

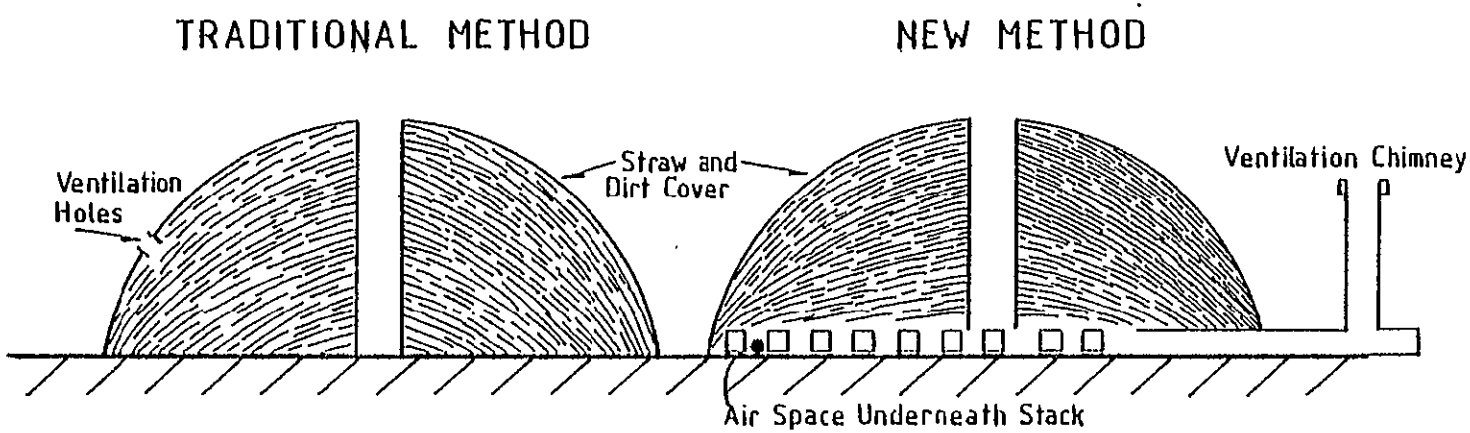


FIGURE B-6 Comparison of traditional method with new method. The center hole is plugged up after the start of the fire. The ventilating holes are replaced by a ventilating chimney.

This program will continue for 18 months the work that is now going on in the FAO/UNDP project at Ziguinchor. It would begin in Ziguinchor and then be transferred to the Bandia Forest area where the first wood harvest is expected in the fall of 1983. In the meantime, ways would be sought to introduce the improved techniques into current charcoal-producing forests such as Maka-Yop, just west of Koungheul. There would be a budget of $35,000 for local labor, materials and other costs to be incurred in the charcoal program.

References:

[1]CILSS/Club du Sahel, op. cit. It is also shown here that deforestation is one of the major problems of the Sahel. Consequently, reduction in wood consumption is desirable.

[2]Draft Project Paper for the USAID Fuelwood Production Project in Senegal (December 1978).

[3]Etude: Budget Consommation, Vol. I. Université de Dakar, Institut Universitaire de Technologie, 1975. This survey of 2312 households in Dakar found that 93% used charcoal as the principal source of energy for cooking.

[4]Project Senegal-FAO/PNUD: Mise en Valeur des Forêts de Basse et Moyenne Casamance et Assistance au Service Forestier.

7. Wood-Burning Cook-Stove

Sahelians consume 3 to 5 times more energy per person for cooking than do the people of developed countries (1). This is primarily because of the low heating efficiency of open fires which are said to be 3% to 12% efficient (1,2). By contrast, a gas stove can have an efficiency of 50%. It is clear that the development and introduction of efficient wood burning cook-stoves are in order. Thorough analysis of the cooking situation in the Sahel by the Club du Sahel/CILSS produced a strong recommendation for such a development (1). This recommendation finds support in the discussion paper of French (2). As in developed countries, introduction of more efficient means of energy utilization is the quickest and cheapest way to ease a critical energy shortage.

What should such a cook-stove look like? This can be answered after considering the wood combustion process (3) and the cooking process. When wood is heated it undergoes complex chemical changes resulting in gases

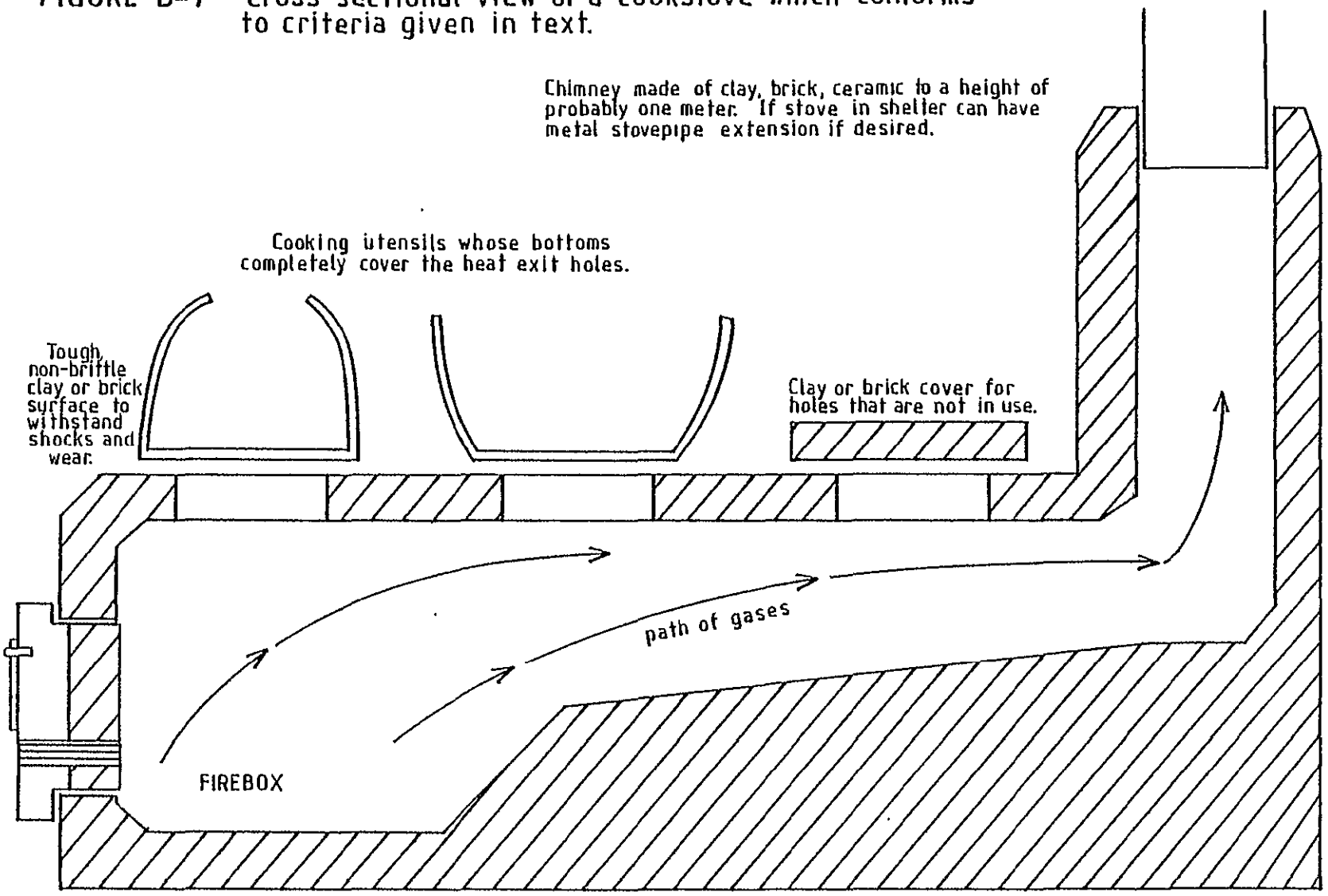
being ejected from its surface. When the gases reach a temperature of about 600°C they begin burning if the right amount of oxygen is available. The solid part that remains begins burning later. In fast burning wood fires about 2/3 of the wood is burned as a gas while in slow burning fires about 1/3 is burned as a gas.

In order for the gas to burn completely it must find itself in a region having a sufficiently high temperature (about 600°C) and the proper amount of air. A lack of air results in incomplete combustion while an excess of air carries off heat that should be used in the cooking. If great enough, the excess air can cool the gas below its ignition temperature so that, again, the combustion would be incomplete. Thus one must control the air inflow rate and the combustion rate.

Firebox walls made of iron can lower the temperature of the gases flowing near the walls and thus produce incomplete combustion. Such walls are also good transmitters of heat to the space around the stove. This is desirable in colder climates but not in the Sahel, where space heating is seldom needed. One wants, as far as possible, to concentrate the heat on the cooking utensil. Firebrick, ceramic, or clay walls, which are better heat insulators, are an obvious choice for cook-stove constuction in the Sahel. A further advantage of such construction materials is their local availability and lower cost. The firebox must be constructed so that the inflow of air can be controlled and the heat directed mostly to the cooking utensil. It must have an appropriate chimney to effect the proper gas and air flows. An example of such a stove is shown in Figure B-7. It satisfies the following criteria.

- Construction with local materials: the iron cover can be made in Senegal,
- Controlled combustion by control of air intake,
- Use of insulating walls to minimize heat loss to the surrounding space and to maintain high temperatures on internal surfaces in order to increase combustion efficiency,
- Placement of the major heat exit in the cooking aperatures, which are completely covered by utensils or, when not in use, by insulating covers. The heat exit aperatures will be as air-

FIGURE B-7 Cross sectional view of a cookstove which conforms to criteria given in text.


Chimney made of clay, brick, ceramic to a height of probably one meter. If stove in shelter can have metal stovepipe extension if desired.
Cooking utensils whose bottoms completely cover the heat exit holes.
Tough non-brittle clay or brick surface to withstand shocks and wear.
Clay or brick cover for holes that are not in use.
path of gases
FIREBOX

Cover with adjustable air inlet: made of iron with clay face for heat insulation. Must be air tight when air inlet is closed.

Walls of firebrick, clay or ceramic: sufficiently thick to reduce heat transmission to acceptable level and to give sufficient strength, yet thin enough to allow user convenient access to cooking surface.

tight as possible to allow combustion control by means of the adjustable air inlet at the firebox entrance.

Stoves based on these design principles have been constructed (4). Some major technical problems remaining to be solved are:

- Finding and preparing the proper clays. Tests for proper clay, proper clay treatment and building techniques have been developed (4).
- Making a standard tight-fitting door for the firebox opening. It could be made at the foundry in Thies.
- Accomodating heating hole sizes to cooking utensil types and dimensions. The utensils should sink down into the holes to receive maximum heat. Iron grills may have to be installed in some holes.
- Optimizing the dimensions of the stove, particularly the firebox and gas passage dimensions.
- Developing standard designs and construction aids that can be widely diffused.
- Adapting designs, as necessary, to fuels other than wood (i.e., peanut shells).

The program will consist of two parts. The first will be development work intended to solve the technical problems. This will be done by the charcoal development team. The Peace Corps will provide a volunteer to work exclusively on the stoves with technical support from the charcoal development team leader.

A budget of $21,000 for the program would cover local labor, materials and equipment, and in-country travel by the volunteer.

In addition to stove development work, there will be a program of stove demonstration and diffusion in villages, described elsewhere. The Peace Corps Volunteer will also participate in that part of the program.

References:

[1]CILSS/Club du Sahel, op. cit.

[2]French, D., "Firewood in Africa," Discussion Paper for the Africa Bureau Firewood Workshop, USAID (June 1978).

[3]Shelton, J., and Shapiro, A.B., "The Woodburner's Encyclopedia," Vermont Crossroads Press, Waitsfield, Vermont (1976). This is the best of the recent books on space-heating stoves using wood.

[4]Information from a telephone conversation with Bob Kemmerle, Civil Engineering Dept., University of California, Davis, CA 95616. Techniques were developed in Guatemala. Such stove development is also recorded in VITA publications and elsewhere.

8. Village Solar Water Heater

Solar water heaters have been developed and are in wide use in many places throughout the world. They are usually for use in areas where pressurized water and electricity are available. In villages of Senegal one must have a water heater that uses neither pressurized water nor electricity. Furthermore, they must be easy to use, correspond to village needs and be very sturdy. A model of such a heater is shown in Figure B-8.

This model has the qualities needed for village use. The flow in the collector -- reservoir loop is by the thermosyphon effect. Reverse flow during the night is prevented by the piping arrangement shown. In order to get warm water a user must pour an equivalent quantity of cool water in the receptacle, thus assuring a constant water level in the reservoir.

This heater has no faucets, no pumps, nor any water level control mechanisms, all of which cause trouble. There are no moving parts. The only maintenance needed is occasional cleaning of the collector surface and cleaning of the screen in the water receptacle. The receptacle cover is necessary to keep dirt, leaves, etc. out of the water receptacle The insulation will be good enough to keep water until morning.

The cost of developing and testing will be $5000. The work will be done by IPM in about one year. The production cost of a 200 leter size will be approximately $500. It will require about 2 square meters of collector. It will be a singly glazed collector of standard type. The structure of the collector and the reservoir will be of cellular concrete.

FIGURE B-8 Model of a Solar Water Heater for a Village.